Highlights in Space

PROGRESS IN SPACE SCIENCE, TECHNOLOGY AND APPLICATIONS, INTERNATIONAL COOPERATION AND SPACE LAW

1993

UNITED NATIONS

A/AC.105/566

Office for Outer Space Affairs
United Nations Office at Vienna

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INTRODUCTION

For many of the world's inhabitants, space activities have become an integral part of everyday life and virtually every country now utilizes space systems for telecommunications, for receiving and broadcasting television and radio signals and for weather forecasting. New applications for space technology are continually being discovered and many of these, such as the use of remote sensing satellites for environmental monitoring and resource management, are playing an increasingly important role in international economic and social development efforts.

This review of recent developments in space science, technology, applications, international cooperation and space law is intended to provide information on these developments to a broad international audience. First published in 1992 as part of United Nations activities undertaken for International Space Year, the publication seeks to increase the awareness of all countries of the benefit of space activities.

During 1993 the pace of international cooperation in space activities accelerated. This was due partly to the dramatically altered international political situation and the growing realization among all countries, developed and developing, that cooperation among countries is vital in a field as complex and expensive as space activities. The year also saw the continuation of many cooperative programmes begun during International Space Year which helped illustrate the viability of broad international cooperation in space applications and science projects.

It is hoped that this publication will make a significant contribution to the ongoing United Nations effort to disseminate information on space activities and to highlight the benefits they provide to all countries of the world.

This publication has been compiled from two reports prepared for the United Nations Committee on the Peaceful Uses of Outer Space. The first part of the report, on space technology, applications, international cooperation and space law, was prepared by the International Astronautical Federation (IAF). The International Institute of Space Law (IISL) provided input for the section on space law. The second part, which focuses on space science, was prepared by the Committee on Space Research (COSPAR) of the International Council of Scientific Unions (ICSU). Many of the most prominent international experts from many countries have contributed to this comprehensive and authoritative survey. The information it contains reflects the wide range of space activities currently being conducted in many national and international space programmes. A list of contributors is located at the end of the report. This publication is being circulated only in the language in which the reports were prepared and submitted.

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PART ONE:

HIGHLIGHTS IN SPACE TECHNOLOGY AND APPLICATIONS, 1993

I. OVERVIEW

The most significant single event in space technology during 1993 was a most unfortunate one: the loss of communications with the United States Mars Observer spacecraft in August, just as it was about to be injected into an orbit around Mars. Data from this spacecraft were to be used to guide the subsequent Russian Federation-led Mars-94 and Mars-96 missions and the United States Mars Environmental Survey (MESUR) later in the decade. Assessment of the consequences of the failure on these missions and evaluation of reflight options are currently in process.

The loss of the Mars Observer, as well as almost simultaneous losses of a United States Titan-4 launcher, the European Olympus satellite, the United States Landsat-6 spacecraft, and the United States NOAA-13 weather satellite, highlighted the significance of a trend toward the use of smaller, less costly spacecraft for science and other missions, a trend that has been driven by budget constraints and risk considerations long before these incidents occurred. A number of such missions were implemented this year; evaluation of their value relative to larger and more expensive -- but more capable -- missions has yet to be made.

Major changes occurred this year in space-station programmes, with an agreement reached in September to join the Russian Federation Mir-2 with the United States-led international station. This action, also motivated by budget considerations in all spacefaring nations, has yet to be fully defined and agreed upon by all participants in these programmes. Constrained budgets also accelerated the trend of the past few years toward joint agreements involving both governments and the industrial firms of many nations in a number of space technologies and applications areas.

Despite these financial barriers, however, substantial progress was made in 1993 toward deployment of new satellite communications services, especially communications with mobile terminals, direct-broadcast of both television and radio, and navigation systems using the now-complete United States Global Positioning System (GPS). Services in all areas were initiated this year, and all will begin to achieve maturity in 1994.

II. SPACE TRANSPORTATION

A. Current Launch Activities

The spacefaring nations conducted 95 launches in 1993: 54 by the Commonwealth of

Independent States , 28 by the United States, seven by Europe's Arianespace, four by China, and one each by Japan and India. Significant space transportation milestones that occurred in 1992-1993 were the 50th Space Shuttle launch, the 50th Ariane launch, the 200th Delta launch, and the 500th Atlas launch.

The McDonnell Douglas Delta-2 continued to extend its excellent reliability record, with five successful launches of GPS satellites for the United States Air Force this year (through September). Delta's current string of 44 consecutive failure-free flights brings its record to 87 successful launches out of 88 during the past 16 years. In April, McDonnell Douglas was awarded the USAF Medium Launch Vehicle (MLV)-III contract for up to 36 launches of the GPS Block 2R satellites beginning in 1996 and extending into the next century.

On 25 March General Dynamics' Atlas-2/Centaur left a UHF-1 satellite, built for the United States Navy by Hughes, in a low, useless orbit due to premature cutoff of the first-stage engine, later traced to a faulty adjustment screw in an oxygen pressure regulator. However, on 3 February General Dynamics released a failure investigation report that clearly identified the Centaur engine problem that had caused two previous failures in 1991 and 1992: pump freeze-up due to air that leaked into the pre-cnilled liquid-hydrogen pump through a faulty check valve just prior to launch. Once the fault had been corrected, the Centaur's RL-10 engines operated flawlessly during the 25 March launch, and also during a successful Atlas-2 launch on 19 July of a USAF Defense Satellite Communications System (DSCS-3) spacecraft and a successful relaunch of the Hughes HS-601 Navy UHF satellite on 3 September. An Atlas E also successfully launched a 1700-kg weather satellite, NOAA-13, into an 860 km polar orbit on 9 August, although the satellite later failed due to loss of power (see below).

The first Titan-4 launch this year, on 2 August, ended in an explosion 101 seconds into the flight, destroying the vehicle and its classified military payload. The failure analysis is not yet complete, but evidence points to an insulation breakdown in one of the two solid-propellant boosters. Titan-4, the largest expendable launcher used by the United States, can carry 17,700 kg to low Earth orbit (LEO) or, with an upper stage, 4,600 kg into a geosynchronous transfer orbit (GTO). The failure was the first experienced by Titan-4 in its seven-flight history. It did not delay the 5 October launch of Landsat-6 aboard a Titan-2, which uses the same core as the Titan-4. That launch was conducted successfully after having been delayed several times for other reasons, but the satellite was lost after launch (see below).

The last two Scout launchers in NASA's inventory were used to orbit the Radcal spacecraft in June and the Department of Defense's (DOD's) MSTI-2 in September. These launches brought Scout's success string to 24, with only one failure in the last 62 launches.

In February Orbital Sciences Corporation's Pegasus successfully launched Brazil's SCD-1 satellite, along with a 15 kg Orbcomm pathfinder satellite. A Pegasus also launched the Los Alamos National Laboratory's Array of Low-Energy X-ray Imaging Sensors (ALEXIS) satellite in April.

Arianespace's Ariane 4, developed by the European Space Agency (ESA), scored five successful launches this year (through September), marking 23 consecutive successes and a total to date of 30 out of 31 Ariane 4 launches. The fleet returned to service on 11 May with the successful launch of Societe Europenne des Satellites' Astra 1C, after a six month hiatus due to spacecraft delays and end-of-year maintenance work. On 22 July an Ariane 44L launched its heaviest payload to date into GTOs: Spain's Hispasat 1B and India's Insat 2B, with a combined mass of 4,141 kg. On 25 June Arianespace won its first launch contract with Indonesia's Satelindo, for the Hughes HS-601 Palapa C-1 scheduled in October 1995. Arianespace has signed a total of 116 launch contracts to date, with a current backlog of 40 satellites on its books. Included in its backlog are the first two Intelsat-8 spacecraft, weighing 3,700 kg, to be launched in 1996.

On 13 January it was announced that the current Ariane fleet will be modified to reduce the propellant reserve in its third stage by about half. The modification, designated H10-3, is a consequence of Ariane's increasing reliability, and will allow a payload increase of the order of 100-120 kg. This brings Ariane 44L's payload capability up to 4460 kg into a GTO. The modification is expected to be completed in 1994.

A unique proposal was made by Arianespace to India on 31 July. In bidding on the launch of Insats 2C and 2D plus an optional launch of an educational platform called Gramsat during 1995-1997 (see below), Arianespace proposed using a Russian Federation Proton vehicle for the 1995 launch, when no Ariane vehicle would be available due to Arianespace's full manifest for that year, with the subsequent one or two launches to be carried out by Ariane-4 or Ariane-5 (other bids were submitted by General Dynamics, in the United States, and China's Great Wall Industry Corporation). Arianespace's partner in the bid was KB Salyut, which designed the Proton vehicle. However, the situation is complicated by the fact that KB Salyut merged with Khrunichev Enterprise (which builds the Proton) subsequent to the preparation of the bid (see below), and Khrunichev's agreement with Lockheed and NPO Energiya (which builds Proton's fourth stage) allows Khrunichev to market Protons outside the Russian Federation only through LKE International, the Lockheed-Khrunichev-Energiya consortium, which is not involved in the Arianespace bid. Regardless of the outcome, the Indian Space Research Organisation (ISRO) plans to choose a launcher by the end of the year.

The 54 launches conducted by the Commonwealth of Independent States in 1992 compare with 59 in 1991 and 75 in 1990. Zenit launches in November and December of 1992 and on 26 March, 1993 were successful, following three consecutive prior failures of the Russian Federation's newest operational launch vehicle. After two successful launches earlier in the year a Proton rocket failed during a Gorizont launch on 27 May due to contaminated propellant in its second stage. The vehicle successfully launched a Raduga geostationary military communications satellite on 30 September, however, and Proton's five-year record remains quite good with 52 successes in 54 attempts. A Soyuz launcher also failed after launch from Baikonur Cosmodrome on 27 April, destroying its military payload.

1993 marked the Russian Federation's entry into the commercial launch service market

when Proton signed launch contracts for Inmarsat-3 and Intelsat-7A. The United States and the Russian Federation signed an agreement on 2 September allowing the Russian Federation to launch of commercial satellites built in the United States with certain restrictions (see below). Prior to the formal agreement, however, the United States had approved launch of the fourth Inmarsat-3 spacecraft, built by Martin Marietta Astro Space (formerly GE Astro Space) of the United States, aboard a Proton. The contract with KB Salyut for that launch was signed on 27 April at a launch price of $36 million, somewhat more than half that bid by General Dynamics and Arianespace for each of the first three Inmarsat-3 launches. The cost to Inmarsat may, however, be considerably higher due to the need to adapt the satellite to the Proton vehicle, the administrative costs of complying with United States technology transfer regulations, and the as yet unknown increase in insurance rate to be established for the launch. The European Bank for Reconstruction and Development agreed in May to provide financial guarantees to assure Inmarsat and its western contractors of smooth progress in preparing for and conducting the launch, which will for the first time introduce Russian Federation space operations to the western commercial world.

ESA also agreed in June to launch its Integral gamma-ray satellite in 2001 aboard a Russian Federation Proton instead of an Ariane-5, although the spacecraft will be built to be compatible with both launchers. The rationale for the selection was the Proton's ability to achieve the desired 48,000 km initial perigee, which is needed to keep the spacecraft above the Van Allen radiation belts, compared to Ariane-5's ability to do so, as well as the expectation that the cost of the Proton launch will be much lower than Ariane-5's sole-customer price of $152 million.

A failure occurred during the 21 December 1992 launch of Australia's Optus-B2 satellite by China's Long March 2E (CS-2E). The cause of the failure, in which the launcher's fairing and the Hughes HS-601 satellite separated prematurely, was not able to be clearly identified. However, Australia and Hughes have decided to use the CS-2E again to launch the replacement satellite. Contracts were signed for CS-2E launches of Asiasat-2 and Afristar, and China used the Long March 2 (CS-2) to launch several recoverable microgravity research capsules and meteorological satellites.

On 25 August the United States announced sanctions denying space exports to China for two years, because Chinese sales of missile components to Pakistan allegedly violated the 1987 international Missile Technology Control Regime (MTCR). Licenses already granted for Chinese launches of Apstar, built by Hughes for Hong Kong's APT Satellite Company, and Intelsat 7A, built by Space Systems/Loral, are not affected, nor are some Hughes components for a domestic Chinese satellite already licensed for export. Licenses under review which will not be granted, however, include one for launching Australia's Optus-B3, built by Hughes, and the one for Hong Kong's Asiasat-2, built by Martin Marietta Astro Space. Upcoming reviews of export licenses for Chinese launches of two more satellites built by firms in the United States, Hong Kong's Starsat and Afrispace's Afristar, would also fall under the two-year sanction.

B. Development Activity

Small launcher development accelerated in 1993, as vehicle builders eyed the ever more promising small satellite market (see below). Orbital Sciences' Taurus, essentially a solid-rocket-boosted version of the aircraft-launched Pegasus, underwent full scale integration tests in Arizona, although its first launch has been delayed until the end of 1993. Development progress of EER Space Services' Conestoga has also been delayed due to budget overruns on NASA's Commercial Experiment Transporter (COMET) programme, for which Conestoga was to be the launch system.

In July Lockheed announced development of a three-vehicle Lockheed Launch vehicle (LLV) family with a total of six variations, able to launch payloads in the small satellite class; i.e., ranging from about 1,065 kg (somewhat higher than Pegasus) to about 4,080 kg (somewhat lower than Delta) into a 180 km, 28.5° orbit. The first launch of the LLV-1 is planned for November 1994.

In 1993 the joint USAF/NASA National Launch System (NLS) programme was cancelled. One of the NLS options was subsequently modified to meet the DOD's urgent need for an operationally resilient launch system. The Spacelifter concept, originally proposed for concept definition funding in the United States' 1994 fiscal year but not included in DOD's current budget planning, is based on a requirement for lifting payloads ranging from about 9,000 to nearly 23,000 kg to a LEO "on demand," at recurring costs less than half those of current launchers.

One reference configuration suggested for Spacelifter consisted of a single-engine 5.5 m diameter core vehicle using the 2.9-MN cryogenic Space Transportation Main Engine (STME). Such a vehicle could lift 9,000 kg to low orbit. For high-orbit (e.g., geostationary) missions either a new cryogenic upper stage or one adapted from Centaur could be used. Payloads up to 23,000 kg (3,600 to 6,800 kg to GTO with the upper stage) could be accommodated via various combinations of strap-on solid-propellant or hybrid boosters, as is done now with Ariane-4. Other operationally oriented elements pioneered by NLS would also be incorporated; e.g., fault-tolerant avionics, automated off-line ground processing, etc. Another near-term Spacelifter option would use the Space Shuttle Main Engine (SSME) to reduce nonrecurring engine development costs, recovering the costly engines and avionics for subsequent reuse via a recoverable propulsion module.

If the United States Department of Defense reverses its plan and does decide to proceed with development, the high-cost elements of Spacelifter, in particular the engine, avionics, ground processing facilities, and tank manufacturing tooling, could be used by NASA and the commercial launch industry for launch systems could be tailored to their specific needs at relatively low additional nonrecurring investment. A Spacelifter-derived vehicle (with engine-out capability) could be crew-rated and used to launch a recoverable personnel carrier of the type currently being explored at NASA's Langley Research Center, thereby eventually replacing the Shuttle's crew-carrying function for Space Station Freedom. Should its future plans for extensive exploration of the Solar System by humans ever mature, NASA could use the already-developed

Spacelifter subsystems to assemble a heavy lift launcher.

Five major space companies in the United States-- Martin Marietta, General Dynamics Boeing, Lockheed, and Rockwell International -- formed an alliance this year to identify technology risks, requirements, conceptual designs, and markets for a next-generation United States launch system. NASA also conducted an Access to Space study to define its projected needs and technology options, especially for the redesigned space station's logistics and support functions (see below).

On 18 August McDonnell Douglas initiated low-speed, suborbital flight tests to demonstrate some of the capability requirements of a vertical-takeoff, vertical-landing rocket-powered single-stage-to-orbit (SSTO) launcher. The DC-X test vehicle, powered by four throttleable RL-10 cryogenic engines similar to those used in the Centaur stage, flew to a 30 m altitude, hovered, and performed a propulsion-controlled soft landing at about 0.3 m/sec 100 m away from the launch site. In a similar test conducted on 11 September, the DC-X reached 100 m altitude and flew about twice as fast as on its maiden flight. Unexpected thrust deviations were experienced during a third test flight on 30 September, but the vehicle did attain its planned altitude of about 360 m and all other test objectives were met.

Although the 0.5 mass ratio of the DC-X is far from that of an orbit-capable SSTO vehicle (which would be of the order of 0.9), the tests this year did demonstrate several key operational characteristics that would be required for cost-effective SSTO launchers. The Single-Stage Rocket Technology (SSRT) programme has been funded by a $68 million contract with the Ballistic Missile Defense Organization (BMDO), which is currently planning a large follow-on supersonic suborbital vehicle known as SX-2, but funds for subsequent development and demonstration efforts have yet to be identified.

Another SSTO programme under development in the United States, the airbreathing National Aerospace Plane (NASP), was cut back sharply as a result of budget constraints to a hypersonic technology programme aimed at resolving NASP's two key technical issues: supersonic combustion ramjet (SCRAMJET) operation and boundary-layer transition, both in the high-teen Mach number range. Discussions were held in December 1992 and December 1993 with representatives of other nations involved in spaceplane research to explore the prospects of an international development programme in this area.

Other SSTO concepts, both employing rocket-powered vertical launch and horizontal landing (like the United States Space Shuttle), were proposed by Lockheed Advanced Development Company and NASA's Marshall Space Flight Center. Lockheed's Aeroballistic Rocket would use a new hydrogen-oxygen engine, modeled after the aerospike ("plug") engine tested extensively over 20 years ago by Rocketdyne, to carry a winged vehicle and an 18,000 kg payload to a LEO. The NASA concept, called X-2000, was opened for comments from industry in the United States on 31 August. The most critical technology required for SSTO success is the propulsion system; NASA is considering the use of the RD-701 dual-fuel ("tripropellant") engine currently being developed by NPO Energomash of the Russian Federation.

Programme details for the X-2000, including funding, have yet to be defined.

On 8 January, Sealar Corporation, a newly formed company in the United States, signed a cooperative research and development agreement with the United States. Naval Research Laboratory aimed at developing the Laboratory's Sea Launch and Recovery (SEALAR) booster. SEALAR is a two-stage liquid-propellant vehicle launched from the ocean surface, with the first stage falling back into the ocean for recovery. Drop tests to determine recovery feasibility were conducted by the Laboratory in 1990.

Development of Ariane 4's successor, Ariane 5, continued, with successful tests of its solid rocket booster, its cryogenic core engine, and its upper-stage engine (see below). Full-scale fairing-separation tests were also conducted. In March ESA signed an agreement with Parachutostroeniya of the Russian Federation for a booster parachute recovery system. The $3 million contract covers test flights of parachute systems developed in cooperation with Spain's Cimsa, Holland's Fokker, and France's Aerospatiale, and a booster recovery parachute for Ariane-5's first flight. Ariane 5, which can insert a payload of 6,800 kg into a geosynchronous transfer orbit (GTO), is scheduled for its first launch in October 1995, with its first commercial flight about one year later.

Europe is also studying a wide range of small satellite launch vehicles. As in the United States, however, budget constraints have caused major cutbacks in long-term technology efforts and in advanced spaceplane programmes such as ESA's Hermes, the United Kingdom's HOTOL, and Germany's Saenger.

Spain plans to enter the fold of spacefaring nations with its Capricornio three-stage solid rocket launcher, which can carry 50-150 kg payloads to LEO. The new vehicle programme was announced in June by the Instituto Nacional de Tecnica Aeroespacial (INTA), along with development of a 300 kg Minisat spacecraft whose first mission, in 1995, will study extreme ultraviolet sources and conduct experiments on materials processing in space.

The first orbital flight of the Russian Federation Start-1 launcher, a modified SS-25 ballistic missile (see 1993 report in document A/AC.105/522), carried a dummy payload to a 700 km orbit on 26 March. Financing for the conversion was provided by companies in the Russian Federation, including IVK and the Komplex division of the Thermotechnics Institute.

The Russian Association for the Conversion of Submarine-Launched Ballistic Missiles set up a joint venture on 10 May with Sea Launch Services of the United States to market Surf, a new commercial launcher using stages from Russian Federation SS-N-20 and SS-N-23 submarine-launched ballistic missiles built by the Makayev Design Office of Mechanical Engineering. The first Surf launcher is scheduled to fly in June 1994. It will consist of an SS-N-20 booster mated with a complete four-stage SS-N-23 Shtil missile (without the warhead) topped by a new payload fairing, and can carry 2400 kg to a 200 km equatorial orbit or 1840 kg to a 200 km polar orbit. Testing of the new vehicle will be performed at Makayev's Severkosmos land-based missile test facility

The Russian Federation announced on 24 March that it is developing the Rus, a successor to the venerable Soyuz family of Soyuz, Vostok, and Molniya launchers. It will use a new control system and onboard computer technology, and will have a new upper stage that provides a payload capability about 800 kg higher than Soyuz's for flights carrying human crews. Rus will be launched from Plesetsk into a 65° orbit instead of from Baikonur (into a 51.6° orbit).

In the Ukraine, NPO Yushnoye announced in June that it was pursuing the development of a new upper stage for Zenit which would allow the launcher to place over 3,900 kg into a GTO. This capability would enable the Ukraine to enter markets served by Ariane-4 and the Russian Federation's Proton.

The Russian Federation's Central Research Institute of Machine Building revealed in September the design of RS-9 Norma, a three-stage heavy-lift launcher based on a winged flyback booster using oxygen-kerosene N-1 rockets from the Soviet Moon programme. Development costs, including launch facilities, were estimated at $1.3 billion. The RS-9, it is claimed, will be able to launch over 76,000 kg into a 200 km orbit early in the next century.

In China, work continued this year on derivatives of the Long March 3 (CS-3). The CS-3A, planned for launch late this year, can carry a payload comparable to Ariane 42P; i.e., about 2,500 kg to GTO. The CS-3B, which adds solid-propellant strap-on boosters to the CS-3A core, is comparable to the Ariane 44L, and is planned for use in launching an Intelsat 7A spacecraft in 1995. China is also developing a small launcher, the Long March 4 (CS-4).

On 20 July Japan's Space Activities Commission recommended continuing development of a winged reusable spaceplane, focused mainly on unpiloted concepts to maximize Japan's expertise in robotics. Current research funding (about $23 million annually) covers three projects: an Orbiting Reentry Experiment, to be launched on the first H-2 flight in 1994; Hiflex, a winged hypersonic test vehicle to follow three years later; and Alflex, an as-yet undefined automated landing experiment. Work on this programme is being conducted jointly by NASDA and the National Aerospace Laboratory.

In December 1992 India conducted final tests of its Polar Space Launch Vehicle (PSLV), which can carry 1,000-kg spacecraft to polar orbit and qualified all four stages for its first launch, which took place at Sriharikota on 20 September. The vehicle's solid-propellant strap-on boosters, solid-propellant first stage, and liquid-propellant second stage all performed as expected, but after second-stage separation the vehicle veered off course. Although the solid-propellant third stage and liquid-propellant fourth stage subsequently ignited and fired normally, the PSLV's 850 kg IRS-1E remote-sensing payload did not reach its proper 817 km orbit. Cause of the failure is under investigation.

The Geostationary Space Launch Vehicle (GSLV) is slated to carry India's 2,500 kg class Insat spacecraft to the geostationary orbit, but development has been delayed due to cancellation in July of a prior agreement with the Russian Federation for the required cryogenic engines and technologies.

III. UNMANNED EARTH ORBITAL ACTIVITIES

A. Telecommunications

1. Fixed Base Communication Systems

Intelsat's Board of Governors took an unprecedented step on 15 September when it decided to procure and operate Intelsat's first regional landmass satellite system. Three new Intelsat 8 and 8A spacecraft will be obtained at discount prices from Martin Marietta in settlement of Intelsat's claim for the improper launch of Intelsat 603 in March 1990 (see below). A Russian Federation Express satellite will also be leased for five years, beginning in June 1994, to support the new system, which will serve China, the Republic of Korea, and most of Japan. Over half the capacity of the Express satellite had been sold by the end of 1993.

In December 1992, engineers at the David Sarnoff Research Center in Princeton, New Jersey, United States, demonstrated key technologies needed to send, receive, and decode compressed multiprogramme television signals for Hughes' DirecTv 150-channel direct-broadcast system (DBS). Demonstration of these digital-compression capabilities constitutes "proof of concept" for an economically viable direct-broadcast system. On 7 January DirecTv signed two major customers: Paramount Pictures and the Disney Channel. In September, Hughes announced that it is also planning a video-telephone system using a follow-on to the DirecTv satellite system, with images generated by a video camera and received on a full-size television set. The new satellite would have 48 narrow-focus spot beams and would use onboard information processing. The high bit rate required would be obtained by digital compression and use of the high-frequency Ka-band.

Besides Hughes Communications' DirecTv, which will use HS-601 buses carrying 16 120-W transponders, three other companies in the United States are developing DBS services: United States Satellite Broadcasting Company, which expects to start service in 1994 using DirecTv transponders leased from Hughes; EchoStar Satellite Corporation, which has contracted with Martin Marietta Astro Space to build two DBS satellites for service beginning in 1995; and Tempo Satellite, Inc., whose $400 million contract with Loral provides for two DBS satellites, each having 32 high-power (107-W) transponders, to be delivered in 1996. A new company, Continental Satellite Corporation, announced in August the award of a $250 million contract to Intraspace for two DBS satellites for service to begin in mid-1966. Although Continental is one of the nine companies licensed for DBS service by the United States Federal Communications Commission (FCC), it has yet to establish funding for the effort and its contractor, Intraspace, has never built a communications satellite.

On 13 January the firm TV Answer of the United States signed a contract with Hughes Communications for the first satellite television network to market merchandise, food, banking services, and entertainment directly to consumers via a two-way interactive communication system. The company began test and demonstration operations using a Ku-band transponder aboard the Hughes SBS-6 satellite, and later changed over to the new Galaxy 4 Hughes HS-601

satellite launched by Ariane in February. Galaxy-4's coverage includes all of the United States, including Puerto Rico.

The United States Advanced Technology Communications Satellite testbed, launched 12 September aboard the much-delayed Space Shuttle Discovery mission (see below), will spend two years demonstrating key technologies for next-generation communications spacecraft, including Ka-band (30-20 GHz) operations, very high-gain multiple-beam hopping antennas, and on-board switching. These technologies, some of which are already being incorporated into commercial satellites currently being designed and developed, can triple communications capability without increasing satellite mass. Seventy-two experimenters have signed up to conduct tests of the satellite's new technologies.

On 6 November 1992 NPO Energiya and Vympel, a Russian Federation ground station manufacturer, announced a joint venture named Globis, financed by the Russian Federation Telebank. Globis is based on an earlier global system proposal, Marathon, which consisted of three geostationary-orbit spacecraft and eight in Molniya orbits. Each Globis satellite would weigh 19,000 kg, based on the premise that complex satellites allow small, cheap earth stations, and would operate in the L, C, and Ku bands.

Another joint venture involving firms in the Russian Federation was announced in December 1992. The Moscow company Global Information Systems (GIS) teamed with the Philippine company Communication and Broadcast Managers Inc. to create Galaxy Satellite and Telecommunications Ltd, based in Hong Kong. Financed by banks in the Russian Federation and other companies, Galaxy contracted with Russia's NPO Lavochkin for three satellites to be launched by Proton vehicles between January 1994 and January 1995. Two of the satellites have 16 Ku-band transponders and will serve the Asian region; the third, for Philippine service, carries eight Ku-band and eight C-band transponders. GIS also announced on 5 April that a network of five new Coupon satellites, financed by the Russian Federation's Central Bank, will be built by Lavochkin to connect banks in the Russian Federation with each other and with foreign banks. The Coupon spacecraft, which will employ some technologies from Russian Federation Geizer military data relay satellites, are to have 16 transponders and will use traveling spot beams, which, for the first time on a commercial satellite, will be focused by the phased-array antennas often used on military satellites. First launch, to a 55° east longitude position in the geostationary orbit, is scheduled for February 1994 aboard a Proton, with successive launches following at six month intervals.

The Canada-Russian Federation joint venture SovCan Star Satellite Communications Inc. of Ontario, Canada, announced on 23 February an expansion of its two satellite system for providing services to the Russian Federation to five satellites, three for domestic and two for international traffic. The expansion was requested by the Russian Space Agency and the Russian Federation Ministry of Posts and Telecommunications. SovCan Star was founded in 1990 by a Russian Federation consortium which will provide the satellite buses and launch services and a Canadian consortium which will build the payloads. Initiation of service was delayed by the 27 May failure of a Proton launcher to orbit the Gorizont satellite that SovCan Star planned to use

on an interim basis. Its replacement was scheduled to be launched in October. The first of the company's dedicated Express satellites, being built by NPO-PM, is planned for launch in 1996.

In November 1992 Germany's Deutsche Aerospace scaled back plans for a dedicated three-satellite Romantis satellite network between Moscow and the West, opting instead for purchasing Intelsat capacity via Deutche Bundespost Telekom. The third partner is the Russian Federation firm Business Sviaz.

France and Germany had agreed on 4 December 1992 to build a direct broadcast pre-Europesat satellite, Europesat 1, to become operational early in 1995. France was to have used four of its channels, Germany eight, and Switzerland one. The satellite was to be built by Matra Marconi Space for Eutelsat, which manages the Europesat programme. The total system, consisting of the satellite, its launch, and ground stations, would have cost about $250 million. However, in May Germany's Telekom decided to terminate its participation in the entire $1.2 billion Europesat programme, which subsequently was terminated. Telekom will continue to use three Kopernikus satellites and one TV-Sat; France Telecom will use its two existing Telecom-2A and 2B spacecraft, will launch Telecom-2C in 1994, and in September ordered a new Telecom 2 satellite for delivery in 1996. Nevertheless on 2 July Eutelsat was requested by its signatories to prepare bid proposals for a new European direct-broadcast satellite to be operated by Eutelsat, nicknamed Hot Bird Plus. One proposal calls for a satellite with 20 transponders; the other for one with 14.

ESA's Olympus satellite began spinning uncontrollably on 12 August during the Perseid meteor shower, although there is no clear evidence that a collision occurred. Because much of the spacecraft's maneuvering propellant had been used in a previous salvage operation in May 1991, there was not enough left to correct the violent spin. Hence ESA, in accordance with international agreements to reduce space debris (see below) moved the spacecraft into a lower "graveyard" orbit on 1 September, and terminated its operations a full year short of the satellite's five year design lifetime.

In March Norwegian Telecom initiated a DBS system for its customers in northern Europe using the Marcopolo satellite purchased from British Sky Broadcasting in 1992. The satellite, renamed Thor, was moved from 31° west longitude to 1° west for Scandinavian coverage. Norwegian Telecom expects to be able to compete successfully with Astra because of the smaller antennas required for its satellite (45 cm vs 75 cm for southern Norway, and 70 cm vs 120 cm for more northern regions).

Italy's Temisat, a 32 kg data relay satellite, became the first western spacecraft ever orbited by a Russian Federation rocket when it was launched by a Tsyklon from Plesetsk on 31 August as an auxiliary payload to a Russian Federation Meteor-2 weather satellite. The Telespazio spacecraft will transmit ocean pollution, rainfall, and other data from about 1,000 surface-based sensors to 50 collection centres for five years, beginning in 1994.

The Arab Satellite Communications Organization (Arabsat) finally signed a contract with France's Aerospatiale on 17 April for two new design Spacebus 3000 satellites, including launch of one of them by Ariane in March 1996, for $258 million. This agreement superseded a prior (September 1992) letter of agreement between Arabsat and Hughes. British Aerospace was the third bidder. The very short 35-month delivery schedule requires Aerospatiale to modify its manufacturing procedures substantially. At 2,415 kg, the Arabsat-2 spacecraft will be the largest ever built in Europe. Aerospatiale has guaranteed a 12-year lifetime, with enough propellant to last 15-16 years. The Arabsat-2 will carry 22 C-band and 12 Ku-band transponders and use 5 kW of power.

On 1 January 18 former Eastern bloc broadcasters joined the European Broadcasting Union (EBU), bringing EBU's membership to 60, located in 47 European and North African countries. EBU also has 55 associate members outside its broadcast area. The union now uses four transponders on Eutelsat 2 to provide service to its customers, and can transmit to antennas with diametres down to 5 m.

On 1 December 1992 Japan's Superbird A, built by Space Systems/Loral, was launched by an Ariane-4 to replace a previous Superbird A that failed in orbit late in 1990. China bought the eight year old GTE Spacenet 1 on 2 December to augment its domestic transmission capacity. The design lifetime of the satellite is 11 years.

The Tokyo-based Broadcasting Satellite System Corporation was formed on 13 April to buy and launch two Ku-band direct-broadcast satellites by 1998. Partners in the new consortium are Nippon Hoso Kyokai (NHK), Japan Satellite Broadcasting, Inc., five other Japanese broadcast companies, and eight banks. The new BS-4 satellites will replace NHK's current BS-3A and BS-3B direct-broadcast satellites.

Rimsat Ltd. began offering services to the Asian market in September, employing a used Gorizont GSO satellite purchased from the Russia Federation which was moved to its new orbital position on 23 July. Two additional Gorizonts are on order, and if business grows as expected, Rimsat expects to purchase four new, as-yet untested 2,500 kg Express satellites from NPO-Priknadloi Mekaniki's (NPO-PM's) Krasnoyarsk-26 factory, which also manufactures the Gorizonts. Gorizonts carry one Ku-band, 1 L-band, and six C-band transponders; the Express is expected to be equipped with 12 C-band and 12 Ku-band transponders. It will use improvements developed for former Soviet Union military satellites, and is expected to benefit from Western satellite technology, including those recently moved from the United States Munitions List to the Commerce Department's Control List, to extend both its capacity and lifetime (the current Gorizonts are designed to last only one year). It is relevant that NPO PM will have access to Spar Aerospace and other Canadian firms well versed in Western satellite technology through its participation in SovCan Star (see above). On 17 March Intelsat also announced signing an option to lease three Express satellites from Informkosmos, beginning in mid-1994.

On 16 December 1992 Argentina's National Telecommunications Commission began

negotiations with a European consortium, Paracom S.A. of Buenos Aires, for its Nahuel satellite communications system to service Argentina, Brazil, Chile, Paraguay, and Uruguay. The European group, consisting of Germany's Deutsche Aerospace, France's Aerospatiale and Alcatel Espace, and Italy's Alenia Spazio, will build the system, whose satellites will be based on the 2,000 kg Eutelsat-2 design. Until the new satellites are ready, Paracom's subsidiary Paracomsat contracted on 19 January with Telesat Canada to provide services beginning 1 June using 23 transponders on two Canadian spacecraft, Anik C-1 and Anik C-2, which were moved into Argentina's two orbital slots in March. Anik C-1 has about 4-1/2 years of propellant remaining; Anik C-2 has about three years' worth.

2. Mobile Communication Systems

In December 1992 Inmarsat's mobile communications services were extensively employed in Somalia by United Nations troops, international relief organizations, and the news media. Satellite links often provided the only mechanism for communication due to the almost total lack of a local telephone infrastructure in Somalia. Even internal Somali calls to parties only a few kilometres away were made via Inmarsat satellites because of the difficulty and danger of courier service.

Inmarsat estimated that the number of commercial aircraft equipped with satellite telephone links for passengers' use more than tripled in 1993, to about 90 aircraft by the end of 1993. The growth spurt resulted from the introduction of multichannel systems, the first of which, a three-channel system called MCS-3000 developed jointly by the UK's Racal Avionics and Honeywell Inc. in the United States, became available in June. The four-channel Toshiba ASAT-1 was introduced in September. Japan's NEC also introduced on 24 May a 13 kg battery-operated suitcase-sized terminal for Intelsat-M telephone and facsimile service, priced at $25,000, and Magnavox Nav-Com Inc. in the United States unveiled its similar 12 kg MX-3030 Magnaphone at prices starting from $20,000.

The 43,000 km round-the-world BOC Challenge sailboat race in 1994-95 will use the Galaxy Inmarsat-C GPS system built by Trimble Navigation of the United States for communications (via Intelsat) and navigation (via GPS). The race starts from the east coast of the United States 1994.

On 1 March six Inmarsat contractors began exploring various options for satellite-based mobile telephone services. The organization's Project 21 committed about $10 million to the studies, which considered systems in low, medium, and geostationary orbits. GSO system studies of a four satellite constellation plus one spare, each weighing about 4,000 kg, were conducted by Martin Marietta teamed with France's Matra Marconi Space, and by Hughes Space and Communications teamed with British Aerospace and Japan's NEC Corporation; medium-orbit systems (12 satellites and three spares, each weighing about 2,000 kg, at 10,350 km altitude in a 50.7° orbit) were evaluated by TRW and the Martin-Matra team; and studies of low-orbit options (54 satellites and nine spares in a 1,800-km, 55° orbit) were conducted by India's Antrix Corporation and a team of France's Aerospatiale and Alcatel, Italy's Alenia Spazio, and

Germany's Deutsche Aerospace. All systems had to be capable of operating with 500-mW hand-held telephones. The goals of the studies were to determine the suitability of the variou systems, propose potential spacecraft designs, estimate the size of the market, and gauge th preferences of potential customers. Inmarsat subsequently dropped the low-orbit option on 2 July because of its high estimated costs, renamed the new system Inmarsat-P, and announced tha selection of one of the two remaining options would be made in late 1993 or early in 1994.

The American Mobile Satellite Corporation (AMSC) enjoyed two market successes i July. Southeastern Freight Lines, Inc. signed a multi-year contract for mobile communication and tracking services using AMSC's Skycell Fleet Management service. Southeastern Freight ha 1,200 trucks and 40 terminals serving over 6,000 cities and towns in the southeastern Unite States. AMSC also signed distribution agreements with 60 cellular telephone services whic collectively serve 633 markets having a population of 152 million. AMSC will use dual-mod phones, built by Japan's Mitsubishi Electric Co. and Westinghouse Electric Co. of the Unite States, that automatically route calls via their satellite when the user is out of range of th terrestrial network. The eight-members of the AMSC consortium also reached their financin goals this year, with $346 million being committed by McCaw Cellular Communications (sinc merged into AT&T) holding 32 per cent; Mobile Telecommunication Technologies Corporatio (Mtel) holding 10 per cent; Hughes Communications holding 29 per cent; Singapore Telecom holding 19 per cent, and the remaining 10 per cent being shared among General Dynamics Battery Fund, Metro Media, and individual investors.

On 2 August Motorola finally assembled the first round of necessary funding, some $80 million from 28 investors worldwide, to proceed with its 66-satellite Iridium system for globa service via hand-held telephones. Investors include Motorola itself, with 34 per cent; a Japanese consortium of about 20 companies led by Daini Denden (DDI) and Kyocera Corporation, with 15 per cent; two Saudi Arabian groups led by the Mawarid Group, with 15 per cent; four telecommunications companies, Sprint Corporation of the United States, Canada's BCE Mobile, Italy's Societa Finanziaria Telefonica per Azioni (STET), and Thailand's United Communications Industry Company, which together hold 5 per cent; Venezuela's Muidiri Investments BVI Ltd., with 5 per cent; and two launch-service companies, Khrunichev Enterprise of the Russian Federation and China's Great Wall Industry Corporation, both of which have signed agreements to launch part of the satellite fleet, with 5 per cent each (the balance of the constellation is expected to be launched by McDonnell Douglas Delta rockets). India's Infrastructure Leasing and Financial Services (ILFS) subsequently (on 9 September) agreed to buy a 5 per cent share for $40 million and invest another $40 million in 1995. Launches of the 750 kg satellites, being built by Lockheed under a $700+ million contract for 125 spacecraft, are expected to begin in 1997. Both Lockheed and antenna contractor Raytheon of the United States (with a $300 million contract) also own small equity holdings. Khrunichev will reinvest $40 million of the launch fees it receives for launching 21 Iridium satellites aboard three Protons launched from Baikonur Cosmodrome in Kazakhstan. In its 23 January joint-venture contract, Khrunichev also agreed to upgrade the Plesetsk launch site in the Russian Federation so it can handle the company's SS-19 missiles, modified to launch individual Iridium spacecraft as needed. Motorola plans to seek an additional $800 million within the next two years for its next round of financing of the

$3.4-billion Iridium system.

On 14 January the United States FCC approved the spectrum allocation for small satellites in the United States and issued preliminary rules for the use of that spectrum. The three applications on file were those of Orbital Sciences Corporation's subsidiary Orbital Communications Corporation (Orbcomm), Starsys Global Positioning, Inc., and Volunteers in Technical Assistance (VITA). Orbcomm's concept stresses low cost two-way messaging using pocket-sized transmitter-receivers communicating via 26 small, 40 kg satellites in 785 km orbits. Applications also include emergency communications for automobiles, monitoring of industrial assets and stolen vehicles, truck fleet management, and electronic-mail communications. Joint financing agreements on the $135 million system were signed on 26 July by Orbital Sciences and Canada's Teleglobe Inc., which will invest $80 million and handle marketing outside the Unites States. Orbcomm plans to orbit the first two satellites, designed for a lifetime of four years, on a Pegasus launch early in 1994 and complete the constellation in 1995. The Starsys concept, embodied by 24 satellites in 1280 km orbits, focuses mainly on industrial applications such as asset monitoring and data collection from transmitters installed in shipping containers, vehicles, and remote locations. It is expected to cost about $150 million and become available for service in 1995. The first system in orbit is likely to be VITA's, whose two small satellites, built by the UK's Surrey Satellite Technology Ltd., are to be launched in late 1993 and early 1994 as auxiliary payloads aboard Ariane launchers. They will transmit data to, and receive data from, relief organizations in developing nations worldwide.

Details of the Orbcomm satellites were released in September. They will use Orbital Sciences Corporation's 40 kg disc-shaped Microstar bus, which is only 16 cm thick and which can be stacked eight at a time aboard Pegasus XL launchers. The spacecraft will be deployed from the Pegasus carrier by springs, which will space them evenly in their 785 km orbital planes. Each of the $1 million satellites generates 230 W of power and has 17 data processors and 7 VHF and UHF antennas, allowing it to process 50,000 messages per hour. Subscriber handsets are expected to cost from $50 to $400.

France's space agency CNES also decided on 16 September to proceed with its five satellite Taos two-way messaging and position-location system, whose operational concept was verified by the experimental S80-T pathfinder satellite launched in August 1992. The 130 kg spacecraft will orbit in five different orbital planes at 1300 km.

In what could be a landmark action to streamline the current complex licensing process for mobile communications systems, the United States companies Motorola and Globalstar, whose systems employ different technologies and will be in competition with each other, filed a joint proposal with the FCC on 7 October. Their proposal recommends that LEO systems be assigned spectrum allocations only when they become operational; that is, when half the system's satellites are in orbit, and that the available frequencies be shared equally with new LEO systems as they are launched and become operational. Financial qualification standards would also be imposed on all applicants to eliminate unqualified candidates. If the recommended action is taken, it would be a major step toward integrating the hand-held telephones of all mobile systems into a

global network. However, the proposal has been opposed by three companies in the United State TRW, Ellipsat, and Constellation Communications.

In February a new United States satellite telephone company, Calling Communication Corporation, filed a license request to the United States FCC for a high-frequency, 840 satellit system to provide global service to portable telephones. Company representatives reporte financial backing from AT&T and McCaw Cellular Communications, Inc., which subsequentl merged in August to form the world's largest communications enterprise. The 750 kg satellites each equipped with 189 active phased-array antennas, are to be launched into 21 sun-synchronou orbital planes each containing forty equally spaced spacecraft plus four spares. They will use th 30/20 GHz Ka band.

The vagaries of financing mobile satellite systems in the current fiscal environment wer illustrated on 5 April, when Canada's Telesat Mobile filed for bankruptcy after both a Canadia bank group led by the Canadian Imperial Bank of Commerce and a French group led by Credi Lyonnais withdrew over $200 million of financing. On 3 June, Telesat Mobile's creditor approved a plan for Canada's communications giant, BCE Inc., to invest $94 million in exchang for eventual ownership of the company, renamed TMI Communications, allowing the first MSA launch to proceed late in 1994 (it was originally scheduled for May 1994).

On 15 December 1992 five United States firms filed requests for licensing satellite radi broadcast systems aimed at automobile and individual-household customers, joining the sol previous license requestor, Satellite CD Radio. The new license applications were from Digita Satellite Broadcasting Corporation, with 512 radio channels from a single satellite beginning in 1998; American Mobile Radio Corporation, with 11 compact-disc (CD) quality channels and 1 others from two satellites; Loral Aerospace Holdings, Inc., with one satellite providing 3 commercial-free CD-quality channels; Primosphere L.P., with 23 CD-quality and six non-musi channels from two satellites; and Sky Highway Radio Corporation, with 30 channels from a single transponder aboard the second Echostar satellite. Afrispace Inc., which received an experimental license from the United States FCC in 1991, has postponed its intended 1993 launch to 1995 due to regulatory delays and a slower-than-expected pace in raising the necessary capital. The company has signed three customers to date: Radio Nederland (three channels), Multiradio of Paris (one channel), and the Kenya Television Network (one channel).

As part of its new applications-oriented agenda for space activities through the end of the century, announced in April, the Russian Federation is designing a new mobile-communications system called Marathon, consisting of constellations of Arkos geostationary-orbit satellites operating in conjunction with Molniya (elliptical)-orbit Mayak spacecraft. The system is planned to provide 1,800 to 2,000 communications channels by 1996.

3. Navigation and Position Location

The United States Global Positioning System (GPS) achieved full global coverage for navigation on 21 July, after a successful satellite launch by a Delta-2 rocket on 26 June. At that

point the GPS constellation consisted of 21 production satellites and three research and development spacecraft. The final system will have 24 production satellites and three spares, each orbiting the Earth every 12 hours and broadcasting precise time signals for ground, sea, air, or space-based receivers to use in establishing their exact location.

The United States Federal Aviation Administration (FAA) on 9 June approved the use of GPS satellite navigation signals over oceans and during non-precision (Category II) landings by pilots in the United States. Until the Air Force declares the GPS system fully operational, which should occur soon, pilots are permitted to use the GPS signals only in conjunction with other FAA-approved navigation aids.

FAA standards for GPS receivers were issued in December 1992. Once the GPS system is operational, panel-mounted GPS installations costing $2,000 to $5,000 will be able to replace current navigational systems which cost up to $20,000. Continental Airlines is likely to be the first to use the GPS-only system, on ATR-42 aircraft due for certification by year-end, for its Colorado operations. The United States company Garmin International introduced two new GPS receivers designed to provide private and business aircraft pilots with course and distance information for destinations and waypoints. The GPS-150, which is priced at $3,995, is installed in the aircraft's instrument panel; the portable GPS-95 AVD, priced at $1,795, provides a moving map display showing the aircraft's course and position relative to landmarks. Trimble Navigation also markets its TNL-2000A panel-mounted receiver in conjunction with the company's ground-based TNL-2800 Landing and Tracking System.

The capabilities of the GPS-based aircraft navigation system were graphically demonstrated on 14 September, when a Gulfstream-4 business jet airplane took off from Washington's National Airport, flew a 20 km curved course, and executed a perfect landing, guided solely by GPS signals. Except for takeoff and landing, when the pilots had to respond to air traffic controllers' directions, the entire flight was made with the pilots' hands off the controls, the GPS signals guiding the plane directly through its automatic pilot. A week earlier, a series of tests performed by the Aircraft Owners and Pilots Association in the United States, using a Beech BE-36 Bonanza airplane, demonstrated that GPS navigation was superior to the existing Instrument Landing System (ILS) for instrument approaches.

Two companies in the United States, Magnavox Electric Systems and CUE Network Corporation, created the Pinpoint service which uses a combination of GPS signals and transmissions from local FM radio stations to determine customers' position location within 1-2 metres. The system, which measures the error in satellite signals (differential GPS) and transmits the corrected signals over unused FM frequencies, went into service in Los Angeles, California, in February and has since expanded to 50 other cities in the United States. Pinpoint's receiver, about 12x15x5 cm, costs $300, and the company's annual service fees are expected to vary from $300 to $1,200. Norway also announced a differential GPS system, SATREF, which offers 5 m resolution by broadcasting GPS correction data over AM and FM radios. The first users of the system are expected to be helicopters and small aircraft.

On 25 November 1992 Japan formed the GPS Council to coordinate information, including software standardization, among the Japanese companies which manufacture commercial devices for use with GPS systems. The Council will also represent Japan's industry in trade discussions with manufacturers in the United States. On 7 September Japan's Ministry of Transport announced a $1 billion programme to supplement the United States GPS and the Commonwealth of Independent States Global Orbiting Navigation Satellite System (GLONASS). The plan calls for two relay satellites and two ground stations for air-to-air and air-to-ground monitoring of satellite position information in the Pacific rim region from Alaska to Australia. The first satellite would be launched in 1999; the second in 2004.

In December 1992 the Euteltracs system for sending and receiving messages and position location via Eutelsat spacecraft was tested for use aboard European fishing boats on a 3,700 km journey from Newfoundland, Canada, to Rostock, Germany. As of the end of August, the International Maritime Organization has required all ships displacing more than 300 English tons to install satellite-based position-reporting beacons.

On 1 March a new company in the United States, Mobile Datacom Corporation, filed an application with the FCC for using Radio Determination Satellite Services (RDSS) equipment acquired by Comsat from Geostar Corporation, which terminated operations in 1991. The new company will use an Earth hub in Clarksburg, Maryland, and lease space on Spacenet-3 and GSTAR-3 satellites from GTE Spacenet. Ground terminal costs for vehicular or hand-held customer use are claimed to be less than $1,500.

B. Remote Sensing

1. Earth Observations

A report issued by the United States Congress Office of Technology Assessment (OTA) in June recommended that the United States explore merging all its remote sensing systems, currently operated separately by DOD, NASA, and the National Atmospheric and Oceanic Administration (NOAA). These agencies plan to spend about $30 billion on remote sensing systems over the next two decades. Significant savings might be achieved, according to the OTA report, by merging the programmes. United States Vice President Al Gore subsequently requested the agencies to take this action in his National Performance Review released on 7 September.

The United States suffered a major setback in its Earth observation capability when all communications with Landsat-6 were lost shortly after its launch from Vandenburg on 5 October aboard a Titan 2. Because Landsat-4 and Landsat-5 are nearing the end of their lives and Landsat-7 is not scheduled for launch until March 1998, the Earth Observation Satellite Company (Eosat), which operates the Landsat system, plans to fill the gap by marketing imagery from other satellite systems.

The United States Commerce Department issued the first private remote sensing operating

license on 2 February to World View Imaging Corporation, which plans to launch two Earth observation satellites by 2000 in partnership with CTA Inc. The low-altitude 200-250 kg craft will have 3 m resolution, and the system will feature fast electronic ordering and distribution that will enable image updating in one or two days. In September CTA sought permission from United States government agencies to launch the satellites with Russian Federation Start-1 vehicles, converted from SS-25 missiles, from the Poker Flats Research Range in Alaska.

On 10 June Lockheed Missiles and Space Company also announced a high-resolution (1 m) Commercial Remote Sensing System (CRSS), based on the company's extensive experience in building military reconnaissance satellites. In its application for a license, Lockheed noted that in May the University of Berlin had begun marketing images from Russian Federation military satellites with resolution better than 1 m. In June Lockheed initiated discussions with the South Australia Economic Development Authority to explore the use of high-resolution CRSS data. On 19 June the United States company Space Liaison International signed an agreement with Sovinformsputnik of the Russian Federation to sell Russian military images with 2 m resolution.

In November 1992 ESA's member nations approved a long-term $3.6-billion programme of Earth, ocean, and atmospheric observations employing several large sophisticated spacecraft. The ERS-2, the follow-on to the successful ERS-1 launched in July 1991 and still fully operational, will be launched early in 1995. It will be followed in 1998 by the 8,000 kg, $2.2-billion polar platform Envisat, whose ten instruments (twice the number carried by ERS-2) will transmit data to Earth at 200 MB/s. Envisat, which like ERS-1 and ERS-2 will also carry radar sensors, is expected to operate from four to six years.

On 24 November 1992 a French lobbying organization called Eucosat was formed to encourage the establishment of a European agency that would use satellites for both environmental monitoring and military observations. By combining the development of the Helios reconnaissance satellite with that of the SPOT-4 satellite, the French government estimated it will save about $ 240 million.

SPOT Image repeated last year's reactivation of its SPOT-1 satellite from April to late July to provide Europe with imagery to support the crop-growing season. This year, for the first time, the European Community helped finance the operation, paying SPOT Image $400,000, or about one-third the reactivation cost, and also paid for each of the images it uses for its agricultural projects.

On 19 January SPOT Image announced the development of a new generation of SPOT satellites, beginning with SPOT-5 to be launched in 1999 and SPOT-6 in 2005, at a total development cost for the two craft of approximately $1.1-1.3 billion. The resolution of SPOT-5 will be 5 m, vs 10 m of current SPOT spacecraft. The new satellites will provide stereoscopic images (estimated to comprise 20 per cent of the future market); and it will have a 5-7 year design life vs 2-3 for the current fleet. SPOT-3 was launched on 25 September and SPOT-4 is scheduled for launch in 1995.

On 13 May Khrunichev Enterprise of the Russian Federation announced that Almaz-1B, identical to Almaz-1, the first commercial radar satellite, was about 50 per cent complete, and if financing could be secured would be launched in 1996. NPO Machinostroyenia is building the payload, which includes a three-band radar and an optical imager having 2.5 m resolution. Almaz-1 was launched in April 1991 and the 18,500 kg satellite was intentionally destroyed by reentry in October 1992 after its propellant was expended.

Discussions were held in November 1992 on creating a Pacific and Asian regional space organization to coordinate the use of environmental satellites in the region, which experiences about 80 per cent of the world's natural disasters. Although Japan has significantly reduced its prices to government and academic researchers for images from weather satellites, costs remain high. Japan's proposal for an internationally supported 38-satellite constellation called the World Environment and Disaster Observation System (WEDOS) was criticized as being too expensive to deploy and operate.

Australia began operations on November 11, 1992 of a new data processor for ERS-1 radar observations, designated Advanced Equipment to Handle ERS-1 (Aethers). It can receive raw data at 106 MB/s and process it at 10.6 MB/s into clear relief images with a pixel resolution of 20x16 m. It takes about 2.5 minutes to produce an image of 100 km^2.

South Africa revealed a model of its 300 kg Greensat spacecraft in June. It is designed to carry two imaging systems into a 400 km orbit in 1995, a 2.5 m resolution panchromatic imager and a multispectral camera with 16 m resolution optimized for agricultural data. South Africa also announced development of a three-stage solid-propellant launcher, the RSA-4, to carry payloads up to 515 kg to LEO.

From 19 to 30 April the United Nations Programme on Space Applications and the Department for Development Support and Management Services, with financing from the Trust Fund for New and Renewable Sources of Energy and ESA conducted the first of a series of training programmes for 25 remote sensing specialists from 20 African nations in the interpretation of data from ESA's ERS-1 spacecraft. ERS-1's radar observations are particularly useful in Africa because the continent's heavy cloud cover often obscures optical sensors.

The United Nations' International Drug Control Programme, in cooperation with France, the European Community, and SPOT Image, conducted a number of tests this year to evaluate the use of remote sensing satellites in helping to identify and destroy crops such as poppies, coca, and marijuana from which drugs are extracted. Tests included mapping studies in Afghanistan and Thailand, evaluation of the relative effectiveness of satellite images, airborne instruments, and optical or radar instruments; and assessment of the ability to process images quickly enough for authorities to destroy the growing crops.

United Nations peacekeeping troops disembarking in Somalia during December 1992 made intensive use of satellite imagery for deploying troops, designating helicopter landing sites, and establishing amphibious landing areas. Combining SPOT and Landsat imagery with GPS

signals enabled troops to determine their positions accurately, especially in remote country areas. Several United States military reconnaissance satellites were used to determine the locations of warring factions, and their data were combined with civil system imagery from SPOT and Landsat spacecraft to construct accurate maps of Somalia's regions of interest. Satellite images of X-rays and other medically illustrative material transmitted via Inmarsat were used by Army field doctors to consult with specialists in hospitals in the United States. Military photoreconnaissance satellites were also used to verify delivery of air-dropped relief supplies to besieged Muslims in Bosnia and Herzegovina.

In an application similar to that used in Somalia, SPOT Image is combining SPOT and GPS data to produce accurate, up-to-date maps of several cities in the Russian Federation, including Moscow, for use by companies interested in doing business in the Commonwealth of Independent States. The maps, which are needed because available maps of the Commonwealth of Independent States were distorted by the Soviet Union for security purposes, also include overlays of population trends and other demographics.

On 30 November 1992 NASA and the United States Army announced the location of a number of previously undiscovered Earth fault structures in California using SPOT satellite images. SPOT data combined with GPS satellite signals also allowed NASA researchers to track the very small movements produced by earthquakes and continuous fault motion, providing a potentially useful tool for use in earthquake prediction.

Military spacecraft of the Defense Meteorological Satellite Program were used to monitor flooding in the midwestern United States during the summer storms, determining soil wetness with microwave imagers that are able to penetrate clouds to measure Earth-surface radiation data. Both SPOT and Landsat images are in wide use for post-flood assessment of crop loss, changes in farm soil, corruption of sewage systems, the spread of disease, and changes in river patterns and locations. Integration of ERS-1 radar data with visual images made it possible to see the ground under water to determine whether it is cultivated, pasture, or fallow land. Also, superimposing current Landsat photos over comparable photos taken during drought conditions in 1988 provided precise determination of the extent of potential flood damage to forests, farms, cities, roads, etc.

In mid-1993 Landsat images were used to identify forest corridors in Kenya through which monkeys carrying the yellow fever virus travel, spreading the disease widely. Other insect-spread diseases such as malaria (in Mexico) and sleeping sickness (in Uganda) have been similarly attacked by spotting the vegetation indices that appear to accompany outbreaks, with the goal of predicting epidemic trouble spots and taking remedial action before, rather than after the disease breaks out.

During the summer of 1993 the UK initiated five remote sensing application projects selected by the British National Space Centre's (BNSC's) Earth observation directorate. These include sugar-beet crop forecasting, monitoring protected landscapes, measuring ocean wave heights and wind speeds, searching for offshore oil deposits, and analyzing sediment in coastal

regions. The three year pilot projects, funded by BNSC at about $9 million plus roughl matching funds from the participating organizations, use data from a variety of spacecraft; e.g ERS-1, SPOT, Landsat, Topex-Poseidon, and, when it becomes available, Seastar's Sea-Viewin Wide Field Sensor (SeaWiFS).

2. Atmosphere and Ocean Observations

On 1 February the French space agency CNES announced a cooperative programme wit NASA to launch a series of Topex-Poseidon follow-on spacecraft. The follow-on fleet, however would use much smaller, less costly satellites: about 400 kg vs Topex-Poseidon's 2,500 kg. The would continue the larger satellite's five year mission, which started formally late in February of accurately measuring ocean currents, wave heights, wind speeds, and other features of ocea topography that affect global climate changes.

Topex-Poseidon, meanwhile, tracked the El Niño weather condition in the wester equatorial Pacific Ocean. As reported on 26 February, the ocean-observing satellite provided the clearest definition ever of the leading edge of El Niño's warm-water surge, called a Kelvin wave pulse, which reached South America's Pacific coast early in March and caused extremely we weather in April as far north as California and Oregon.

ESA's Meteosat-3 spacecraft was moved in February from its 50° west longitude position over the Atlantic Ocean to a new location over Colombia, where it can image all of North America and therefore more fully complement United States weather forecast services provided by NOAA's GOES-7 satellite. Data from Meteosat-3 and control signals are relayed via a new station at Wallops Island, Virginia, to ESA's ESOC operations centre in Darmstadt, Germany, using a PanAmSat commercial satellite.

The 1040 kg United States NOAA-13 polar-orbit weather spacecraft successfully launched on 9 August to replace NOAA-11 lost power and failed on 21 August, and is tumbling uselessly in its 860 km orbit. The United States will now have to depend on the five year old NOAA-11, which has lost three of its four stabilizing gyroscopes, and reactivation of NOAA-9, which had been turned off when NOAA-13 was launched, until a replacement can be built and launched.

The Total Ozone Mapping Spectrometer (TOMS) aboard the United States Nimbus-7 satellite, in operation since 1978, failed in early May. On 7 June the spacecraft was shut off for a month to give TOMS an opportunity to recover, but it failed to do so. Unfortunately, the only other TOMS in orbit, aboard the Russian Federation's Meteor-3 launched in August 1991, also failed during the second week in June. Because of the TOMS instruments' key role in studying the current abnormally low stratospheric ozone levels, NASA is considering accelerating the July 1994 launch of an Earth Probes TOMS instrument aboard a Pegasus vehicle. The next scheduled launch of a TOMS, aboard Japan's Advanced Earth Observations Satellite (Adeos) won't take place until 1995.

On 5 February the United States announced plans for seeking funds to send several small

satellites into the middle portion of the atmosphere, the last atmospheric region that remains relatively unexplored. ASA's Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) mission would involve launching three or four small satellites on Taurus or Delta rockets beginning in 1998 into both circular and elliptical orbits dipping as low as 130 km. TIMED's data would complement those of the much larger Earth Observing System.

In August Hughes Information Technology Co. of the United States proposed a low-cost Geostationary Environmental Monitor (GEM) weather observation programme, in which 20 kg sensors would be mounted as secondary payloads aboard GSO communications satellites, relaying weather, disaster warning, and other environmental data to both government and commercial users. The sensor package includes a color imager with 1 km resolution and an infrared imager with 3 km resolution, and has a very short update period of about one minute. The cost per package, including integration, is estimated to be $20 million. Hughes plans its first launch aboard a HS-601 bus in mid-to-late 1995.

C. Commercial Developments

The largest space industry merger in history was announced on 23 November 1992, approved by Martin Marietta's Board of Directors on 25 March, and consummated on 2 April 1993, when Martin Marietta purchased GE Astro Space from the General Electric corporation for about $3 billion. The two companies had gross 1991 revenues of over $12 billion and together employ more than 94,000 people. The GE unit currently has a backlog of 64 spacecraft on order and also makes earth stations; Martin Marietta builds the Titan launch vehicle and the Space Shuttle's external tank.

On 1 December 1992 the French rocket firm Societe Europenne de Propulsion (SEP) announced 31 contracts, totalling about $10 million, with space companies in the Russian Federation in liquid-propellant rocket propulsion and composite materials.

On 22 September ESA announced a three year programme called Radius to encourage the use of space-developed technologies by non-aerospace industry. Over 100 companies have expressed interest in the $12-million programme, which is scheduled to begin in January 1994. Similar efforts were established previously in the United States. (NASA's Technology Transfer and Technology Utilization programmes, as well as the 16 Centers for Commercial Development of Space), and in Japan (the Japan Space Utilization Promotion Centre, originally capitalized by the Science and Technology Agency and the Ministry of International Trade and Industry). Growth in Japan has been particularly impressive: from $2.5 million in 1989 to $25 million in 1993. ESA's Radius will focus primarily on materials science, crystal growth, fluid physics, dispersion and filtration processes, cell biology, and physiology.

In December 1992 India established the Antrix Corporation to market and export space equipment. The Bangalore company's eight-person Board of Directors includes representatives of the Indian Space Research Organization, several other space agencies, and three major Indian commercial firms: Bombay's Tata Group, Bombay's Godrej Group, and Hyderabad's Machine

Tools Aids and Reconditioning. Antrix is government-owned and is expected to employ about 50 people.

On 23 December 1992 the United States State Department approved a joint venture between the Lockheed Corporation and Moscow's Khrunichev Enterprises to market Russian Federation Proton rockets to commercial customers. The State Department action was approved by United States president George Bush on 20 January, and the Lockheed-Khrunichev joint-venture contract was signed on 23 January. NPO Energiya later joined the alliance, which was incorporated in the United States in April as Lockheed-Khrunichev-Energiya International (LKE). On 15 September LKE announced that it had signed a contract on 3 August with its first customer, Space Systems/Loral, for one firm launch and four options. The first launch, probably of a Tempo communications satellite (see above), is scheduled for the last quarter of 1995.

Space Systems Loral also announced on 24 September that it had signed an agreement with China Great Wall Industry Corporation to reserve two launch slots at the Xichang Satellite Launch Centre for Long March launches in 1996 and 1997. The agreement was signed before the United States imposed sanctions on shipments to China.

The Ukrainian Space Agency and France's Matra Marconi Space signed an agreement on 5 February encompassing a wide range of cooperative activities on satellite communications in the Ukraine. Although no specific satellite projects were defined, Matra Marconi expects to provide payload and ground stations and Ukraine would build parts of the spacecraft and provide launch services. Matra Marconi also signed a cooperative agreement on 17 June with Canada's Spar Aerospace Ltd. for work on future commercial radar-equipped remote sensing satellites, focusing on advanced onboard processing techniques that would make radar satellites more marketable.

On 7 June Russian Federation President Yeltsin ordered a merger of the KB Salyut design bureau, Proton's designer, with Khrunichev Enterprise, the launcher's manufacturer, into a new organization called the State Rocket Space Centre, located at Khrunichev's plant. The merger is expected to resolve marketing discrepancies due to separate actions taken previously by the two companies.

In February the Swedish Space Corporation and the Norwegian Space Centre announced plans to develop a new commercial launch site near the present Andoya Rocket Range on Andoya Island in Norway. Their goal is to provide launch services for 250 kg class satellites for $5-6 million beginning in 1996, using a new launch vehicle to be developed by PacAstro of the United States.

The Spaceport Florida Authority in the United States received a $2.15 million grant to convert a military missile complex (Launch Complex 46, used for testing Trident submarine-launched ballistic missiles) at Cape Canaveral Air Force Station for use as a commercial launch site. Private sector companies helping fund the conversion, which is expected to see its first use in 1995 when a Taurus rocket is scheduled to launch the Clementine-2 satellite,

are Orbital Sciences, Thiokol, and Honeywell. The Alaska Aerospace Development Corporation also announced plans in August to develop an all-weather launch facility near Fairbanks for launching payloads up to 1600 kg into high-inclination orbits beginning in 1995. Alaska received a grant of $1.1 million for the conversion, which will incorporate existing facilities at the Poker Flat Research Range.

Canada also joined the race for the first commercial spaceport on 17 September, when Akjuit Aerospace Inc. received permission from the province of Manitoba to lease the mothballed Churchill Rocket Range for its Spaceport Canada venture. Akjuit hopes to market the new spaceport for sounding rockets and particularly for small-to-medium sized polar orbit satellites. The company will need financing of about $250 million, which is not yet in place.

IV. MANNED EARTH ORBITAL ACTIVITIES

On 2 December 1992 Space Shuttle Discovery launched its last military payload, apparently a reconnaissance satellite, to an orbit inclination approaching the Shuttle's maximum, 57°. Other experiments, which were not classified, included manufacturing polymer-encapsulated antibiotic ampoules for battlefield use, evaluating the feasibility of laser communications systems, and attempting to deploy six small aluminum spheres to calibrate the debris tracking capability of ground-based radars (including the Haystack radar in Massachusetts, which can detect objects as small as one centimetre in diametre at a distance of 1,000 km). A power supply failure prevented the spheres' deployment, which was postponed to a subsequent Shuttle flight. Discovery landed successfully in California on 9 December.

NASA's sixth Tracking and Data Relay Satellite (TDRS) was deployed from Endeavor, the first Shuttle to fly in 1993, on 13 January, to serve as an in-orbit spare in the event that either of the two remaining operational spacecraft is incapacitated. The 2,300 kg spacecraft was subsequently boosted from the Shuttle's 300 km orbit to the GSO by an Inertial Upper Stage. Endeavor's flight also included experiments to measure X-rays emitted from interstellar gas with the Diffuse X-ray Spectrometer; to determine the mechanism by which muscles atrophy in microgravity; and to test the ability of the Shuttle's fuel cells to be shut down in flight and restarted, which would be necessary during space station deployment. The astronauts also began practicing for space station assembly operations on a five-hour spacewalk in the cargo bay, and demonstrated via a televised linkup to students in four states how toys work in the microgravity environment.

Shuttle Columbia's 25 February flight, carrying Spacelab D-2 chartered by Germany, was delayed a month so that engine pumps suspected of having old seal-retainers could be replaced. A launch attempt on 22 March was terminated on the pad when one of the three main engines failed to start due to a valve malfunction, and the flight was again rescheduled to 24 April. It was finally launched on 26 April. The 88 experiments onboard the Spacelab, mostly German, included testing a new German robot arm as well as a wide range of medical, biological, and materials science experiments. The mission cost Germany $570 million, including $150 million

charged by NASA for use of the shuttle and $10 million due to the launch delays.

During Columbia's standdown, NASA attempted to launch Discovery which carried the second Atmospheric Laboratory for Science and Applications (ATLAS-2) to study the Sun and search for signs of upper-atmosphere ozone deletion, but a 6 April launch attempt was halted 11 seconds prior to takeoff when a valve-closing signal from the main engines was not received by the computer system. It was ascertained that the valve had indeed closed, so the computer was instructed to ignore the false reading and the launch took place on 8 April. ATLAS-2 included a solar constant-measuring instrument (Solcon) built by Belgium's Royal Meteorological Institute and the French Solspec instrument to study the spectral distribution of solar radiation.

Space Shuttle Endeavor carried the first commercial Spacehab laboratory into orbit on 21 June. The laboratory's manifest consisted of 21 NASA experiments, mostly from the Centers for Commercial Development of Space, and one ESA experiment. Japan's Mitsubishi has reserved half a Spacehab module in 1996, at an estimated cost of $40 million. Spacehab charges customers $1.8 million for a single Shuttle flight of a 27 kg experiment. Flights are scheduled at roughly six month intervals. On 25 June Endeavor's astronauts also retrieved ESA's 4400 kg Eureca orbiting laboratory, which had been launched by Shuttle Atlantis on 2 August 1992. The astronauts had to latch Eureca's antennas manually when they failed to retract and latch properly. They used the remainder of their 5.5 hour spacewalk to practice for the Hubble telescope repair mission (see below) before landing on 29 June.

Deployment of the Advanced Communications Technology Satellite (ACTS) was delayed for nearly two months, to 12 September, due to a series of prelaunch anomalies NASA encountered in getting Space Shuttle Discovery off the ground. Reasons for the five delays were a faulty hold-down bolt transistor on 17 July, failure of a hydraulic power unit on 24 July, concern about meteoroid damage from the Perseid meteor showers on 10-11 August, a shutdown of the main engines three seconds before liftoff on 12 August requiring changeout of all three prior to the next attempt, and a two day delay on 10 September to verify that ACTS' transistors were not from the same faulty lot as those which are believed to have caused Mars Observer's failure (see below). After Discovery's astronauts deployed ACTS, a Transfer Orbit Stage then boosted it to a GTO, from which ACTS' onboard thrusters inserted into its geostationary slot at 100° west longitude. The astronauts then released and subsequently recovered the 3200 kg German-built Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer (ORFEUS) satellite. On 16 September they also conducted a six hour spacewalk to practice using over a dozen tools needed for the Hubble repair in December (see below). Discovery made the first night landing at the Kennedy Space Center's runway on 22 September.

The longest Shuttle flight to date began on 18 October when the 15th launch of orbiter Columbia carried a Spacelab into orbit. The 14 NASA experiments onboard the 14 day mission, the Shuttle programme's 58th, continued the life science research undertaken during the Spacelab Life Sciences mission in June 1991, supplementing the earlier cardiovascular and metabolic studies and also exploring the effects of microgravity on the human balance organs. A major focus of the second dedicated United States life sciences mission was investigating the effects

of returning to full Earth gravity; e.g., motion sickness, anemia, and lightheadedness as well as weakened muscles and bones. Columbia's astronauts also photographed and monitored the late-October wildfires in southern California before landing on 1 November.

On 11 December 1992 NASA signed an agreement with NPO Energiya of the Russian Federation confirming the suitability of the Soyuz TM as a crew rescue vehicle for the international space station, stimulating cooperative activity between NASA's industrial contractors and companies in the Russian Federation. Outstanding issues include increasing Soyuz's service life from six months to three years, eventually increasing Soyuz capacity to safely evacuate a crew of eight, and defining suitable landing sites for the Soyuz vehicle.

In January Boeing (United States) and NPO Niichimmash (Russian Federation) announced an agreement to develop life-support systems that may be used on the joint international space station (see below) as well as on future missions. The alliance will build on current Russian Federation systems used on Mir to recycle waste water, generate oxygen, and control temperature and humidity. Hamilton Standard initiated a series of cooperative evaluations of Russian Federation life support equipment in April, beginning with the spacesuits used by Mir's cosmonauts for extra-vehicular activity. Agreements signed with firms in the Russian Federation for this work, which Hamilton Standard expects to lead to joint ventures, include RDPE Zvezda, for lease of space suits and associated equipment; NPO Niichimmash, for testing Mir's water processor, water separator, and a new carbon dioxide reduction system; NPP Nauka, for evaluation of the Russian Federation Buran Shuttle's life-support systems; and NPO Energiya, to test and evaluate environmental control and life-support equipment.

NASA spent most of 1993 preparing for the Hubble Space Telescope repair and maintenance flight scheduled for launch on Space Shuttle Endeavor 2 December. These tasks include installing a new computer memory to replace failed circuits; replacing the solar arrays, which bend and flex when exposed to the temperature shock caused by entering and leaving the Earth's shadow, with new ones built by ESA; replacing the Wide Field Planetary Camera with a new one having built-in corrective optics to compensate for the main mirror's spherical aberration; installing the Corrective Optics Space Telescope Axial Replacement (COSTAR) unit to correct the main mirror's optics for Hubble's other instruments; and replacing two of Hubble's three failed gyroscopes and their electronic controllers. Additional optional repairs include replacing one more gyroscope package, installing a new magnetometer in the spacecraft's position-sensing system, and replacing a power-supply cable. Fortunately, one of Hubble's three fine guidance sensors which had shown signs of failure was returned to service in August and will not need to be replaced. NASA's plans involved five spacewalks over 11 days even though the Shuttle carried enough supplies for eight spacewalks to provide a reserve. The mission was a resounding success.

Space Station Freedom underwent several major reviews and programme reorientations under the new United States administration which took over on 20 January, in an effort to reduce both annual and total costs of the project. Exhaustive studies of three alternative design options were completed by NASA in June, at which time it was decided to modify the configuration only

slightly, with little or no change in the interfaces with the Japanese and European modules, but to institute major changes in programme administration and management to obtain the necessary cost reductions. NASA selected a single centre, the Johnson Space Center, to manage the programme, and a single prime contractor, Boeing Aerospace, to develop and build the modified station design.

"Final" space-station design changes were completed in September (see below), but United States Vice President Al Gore and Russian Federation Prime Minister Victor S. Chernomyrdin signed an agreement on 2 September to merge the United States/ESA/Japan/Canada station with the new Russian Federation Mir-2 space station. This agreement was tied to a more comprehensive Unites States-Russian Federation agreement giving the Russian Federation limited access to the launch market for commercial satellites with United States components and securing the Russian Federation's implementation of the international 1987 Missile Technology Control Regime (MTCR).

The joint United States-Russian Federation space station programme was envisioned as taking place in three stages. First, United States shuttles and astronauts would become involved in upgrading Mir-1's instrumentation, experiments, subsystems, and operating gear. This phase had already begun with last year's agreement on a 1995 linkup of Mir-1 with the Shuttle Atlantis (see below). It would include aid from the United States for replacing Mir-1's solar panels and outfitting the currently grounded Spektr and Priroda modules with life science laboratory equipment and launching them to Mir-1. The United States has agreed to contribute $100 million toward the Russian Federation's effort in this phase. Next, the United States and the Russian Federation would independently launch new modules into a suitable compromise orbit, 51.6°, and link up there. The United States module would be a laboratory module as designed for Space Station Freedom; the Russian Federation one, which would be launched first (in 1997) is likely to be the habitability module planned for Mir-2. The third phase would expand this joint United States-Russian Federation rudimentary outpost into a full station much like that contemplated by the United States (originally Freedom; now Alpha) and by the Russian Federation (Mir-2), incorporating elements from ESA, Japan, and Canada originally planned for Freedom more or less intact. Discussions of this proposed plan are currently in process, not only between NASA and the Russian Space Agency but also within the United States and among Freedom's international partners.

Meanwhile work on the various elements of Space Station Freedom continued. For example, buoyancy-tank tests on a Lockheed-built full-scale model of the Japanese Experiment Module were conducted at NASA's Marshall Space Flight Center from 23 February to 22 March. Also, on 20 September NASA and its current international partners released a space station design based on the studies conducted prior to the 2 September agreement between the Russian Federation and the United States. This station design, called Space Station Alpha, is quite similar to the old Freedom design except that its propulsion, navigation, guidance, and control would be carried out either by a Lockheed military satellite bus (Bus-1) or by the Russian Federation Salyut FGB "space tug;" and assured crew rescue would be provided by two Russian Federation Soyuz vehicles. Should the 2 September agreement be implemented, the Alpha design is

adaptable to integration of Russian Mir-2 modules and solar-thermal power systems. Such a "unified" design, if implemented, would be launched to a 51.6° orbit instead of Alpha's (and Freedom's) 28.5° inclination.

A low cost Early Lunar Access plan to return to the Moon, developed by the United States company General Dynamics, was proposed to NASA in March as a precursor to NASA's First Lunar Outpost plan. The concept envisages the use of existing space transportation capabilities (a Shuttle and a Titan-Centaur) to carry a crew of two to the Moon for 21 days in 1999 at a cost estimated between $6 billion and $13 billion. The future of human space exploration was cast into deep shadow on 26 March, however, when NASA's Administrator closed the Office of Exploration and merged its as-yet unfunded activities into a new office of space science.

The new Russian Federation docking system to be used for the planned 1995 rendezvous of Mir with the United States Shuttle Atlantis was launched to Mir on a modified Soyuz on 26 January. The Androgynous Peripheral Assembling System will be attached to a specially designed docking port on the Kristall module, which has not yet been used for Mir docking operations. NASA, meanwhile, has decided to install an external stripped-down space station airlock in Atlantis's payload bay to mate with the Russian Federation docking system

Cosmonauts Anatoly Solovyev and Sergei Avdeyev returned from the Mir space station on 1 February aboard a Soyuz TM-15 spacecraft after having spent 189 days in space. On 4 February the succeeding team of Mir cosmonauts deployed a "solar sail" 20 m in diametre from a Progress supply vehicle as it left the station. The sail was built by NPO Energiya using funds donated from several firms in the Russian Federation, and was intended as a first space test to evaluate potential future uses of such sails for both propulsion and Earth illumination. The sail was said to be capable of lighting a moving spot on the Earth having an area 4 km in diameter with an intensity of five full moons. Because of the need to conduct another experiment, the reflector experiment was jettisoned after only five hours and began to tumble, but remained visible as a pulsating star for over 24 hours.

Mir cosmonauts Gennady Manakov and Alexander Poleshchuk conducted a spacewalk on 20 April to mount solar collector controls on the outside of the Kvant module. Two more spacewalks, to move solar panels from the Mir core to Kvant to eliminate shadowing and also to make room for the Shuttle Atlantis to dock with Mir in 1995, were delayed until May because a broken handle on the transporter used to move equipment around Mir's exterior had to be replaced (it was carried to Mir in a Progress shipment). These tasks were later accomplished successfully. The two cosmonauts are the first to work under contract -- they each received one million rubles for the three spacewalks.

A French cosmonaut, Jean-Pierre Haignere, spent three weeks aboard the Mir space station beginning on 3 July operating a 100 kg science instrument package. The mission, called Altair, used equipment similar to that used by cosmonaut Michel Tognini in his previous Antares mission a year earlier. France paid NPO Energiya $25 million for the flight and a second one

scheduled for two weeks in 1996. In March ESA also contracted with the Russian Federation for two flights of ESA astronauts to Mir, in September 1994 for 30 days and in August 1995 for 135 days. The cost of the two missions and new experimental equipment for the flights is $71 million. Canada also signed an agreement with the Russian Space Agency on 21 May to fly a Canadian cosmonaut aboard Mir and to open other opportunities for cooperation.

V. SPACE EXPLORATION

A. Astronomy and Astrophysics

On 20 February Japan's Institute of Space and Astronautical Science (ISAS) launched the 450 kg Astro-D into a 550 km orbit, at which time its name was changed to ASCA, a mythological Japanese bird. ASCA carries a large-area X-ray telescope with cameras and an imaging system that can produce images of X-ray activity 10 to 15 billion light years distant. ISAS testing of the spacecraft systems was completed in October, when images taken during the test period were made available to researchers around the world.

Three spacecraft completed a three week search for gravity waves on 11 April, supplementing earlier studies by NASA's Cosmic Background Explorer (COBE) of conditions that led to the formation of the universe. ESA's Ulysses and NASA's Galileo and Mars Observer (which was later lost nearing Mars in August), each in a different region of the Solar System, received and transmitted signals from NASA's Deep Space Network. Scientists are still analyzing the transmissions to detect tiny changes in frequency, which would indicate the presence of gravity waves.

The trend toward using smaller, less costly spacecraft for science missions has been implemented in astrophysical research with NASA's Small Explorer spacecraft series, which are limited to $35 million. Four new candidate missions were selected by NASA in October from 51 proposals. They will be evaluated for 10 months and two will be carried to development and launch aboard Pegasus rockets. The four candidates are the Joint Ultraviolet Night Sky Observer (JUNO), the Positron-Electron Magnetic Spectrometer (POEMS), the Transitional Region and Coronal Explorer (TRACE), and the Wide Field Infrared Explorer (WIRE).

On 16 April astronomers studying Hubble space telescope data reported movement of "Big Bertha," an oval cloud feature in Saturn's atmosphere, which had not been detected by prior ground-based telescope observations. A major gain in understanding the evolution of galaxies resulted from Hubble Wide Field Planetary Camera photos taken late in 1992, showing a remarkable backwards-rotating pinwheel structure within galaxy NGC 7252 containing clusters of newborn stars. The structure is thought to have been created by collision of NGC 7252 with another galaxy.

From March through May five orbiting telescopes were focused on a single astronomical event: the unusually bright supernova explosion SN1993J discovered on 28 March by the

NASA/ESA International Ultraviolet Explorer. The other four telescopes observing this event, which provided the first direct evidence that supernovas herald the death of red giants, were Germany's Roentgen Satellite (Rosat), Japan's Advanced Satellite for Cosmology and Astrophysics (launched on 20 February), and NASA's Hubble Space Telescope and Compton Gamma-Ray Observatory. On 6 May Rosat was reported to have discovered what appeared to be a halo of dark matter around a four-galaxy cluster known as HCG62, casting new light on the long standing debate over the source of the gravitational forces needed to explain the movement of galaxies in the universe.

Data from the Hubble space telescope's high resolution spectrometer released on 21 May estimated the distance to the Sun's heliopause, essentially the radius of the Solar System, at from 82 to 130 astronomical units (AU), which is five to ten times smaller than previous estimates. In August, however, astronomers studying the detection last December by the two United States Voyager spacecraft, currently about 50 AU from the Sun, of a signal apparently caused by a solar wind gust striking the heliopause's bow shock wave, concluded that the heliopause's distance from the Sun is somewhat greater, 116 to 177 AU.

Operations of ESA's Hipparcos spacecraft ended in August after four years in orbit. Despite initial problems in achieving its proper orbit, all the satellite's scientific goals were achieved. Besides plotting 120,000 stars to an accuracy of 1-2 milliarcsec., Hipparcos also conducted high-quality broadband photometry at several hundred epochs for each star, discovered or measured the parameters of 15,000 double star systems, and carried out two-color photometry on about one million stars. Final processed data are to be made available by the end of 1995.

In April, Argentina conducted a critical design review of its first domestically built satellite, SAC-B. SAC-B, a low cost solar-astronomy spacecraft developed jointly with Italy and the United States, will monitor solar eruptions, high-energy X-rays, and gamma-ray bursts. The 350 kg spacecraft, which will use gallium arsenide photovoltaic arrays built by Italy's Fiar, is to be launched by Pegasus in June 1995. NASA will provide two of SAC-B's instruments. Argentina and Italy will each provide one.

B. Earth and Space Physics

When ESA shelved the Aristoteles geomagnetic research satellite due to lack of funds, NASA initiated study of a Gravity and Magnetic Experiment Satellite (GAMES) in cooperation with the French space agency CNES. Plans were announced in March for the collaborative programme, planned for launch in 1998, in which the 260 kg GAMES spacecraft will eject two subsatellites. The first would be released at an altitude of 325 km and would follow 200 km behind the GAMES satellite, which would measure changes for a period of about a year in the subsatellite's speed using laser tracking, accelerometers, and GPS signals, thereby mapping the variations in the Earth's gravity field that cause those speed changes and determining the geoid more accurately. The GAMES spacecraft would then be boosted to a 450 km orbit and repeat the process with the second subsatellite, getting further information on the gravity field to provide insight into the Earth's internal structure and also studying the Earth's magnetic field.

The 114 kg Array of Low-Energy X-ray Imaging Sensors (ALEXIS) spacecraft was launched by a Pegasus vehicle on 25 April, but the United States Los Alamos Scientific Laboratory was unable to establish radio contact with their spacecraft after launch. A television image of the satellite relayed by the launcher showed that one of ALEXIS's four solar panels came loose during the coast between Pegasus's second and third-stage burns. Continuing attempts to contact the spacecraft finally succeeded, establishing intermittent transmissions on 2 June and full operational communications in August, when ALEXIS's mission to monitor narrow bands of ultra-soft X-rays with its six telescopes was initiated. These rays, which originate from the hot interstellar plasma, are several orders of magnitude weaker than medical X-rays. ALEXIS is also scanning the firmament for gamma-ray bursters, and is equipped to measure the effects of the Earth's ionosphere on radio signals.

Los Alamos also disclosed in July that scientific instruments had been carried since June 1989 aboard three secret United States military spacecraft, the Defense Support Programme (DSP) satellites. The Magnetospheric Plasma Analyzers, which weigh only 3.5 kg and consume only 3.5 W, measured the properties and extent of hot plasmas caused by interaction of the solar wind with the Earth's magnetic field at GSO altitudes; the Synchronous Orbit Particle Analyzers measured the characteristics of electrons and ions at these altitudes. These data are important to the trouble-free operation of communications satellites in the GSO.

On 25 May NASA announced the discovery by its 158 kg Solar, Anomalous, and Magnetospheric Particle Explorer (SAMPEX) spacecraft of a new belt of charged particles surrounding the Earth inside the Van Allen radiation belts. Unlike the Van Allen belt, which consists of particles from the Sun captured by the Earth's magnetic field, the new belt is composed of interstellar matter from supernova explosions and possibly the "Big Bang." SAMPEX has orbited the Earth in a 550x670 km orbit since its launch aboard a Scout rocket on 3 July 1992. It was the first mission in NASA's Small Explorer programme. The entire project cost only $60 million, illustrating the value of the current trend to smaller, less costly spacecraft for science and exploration.

In early November ESA's Ulysses spacecraft reached 43° south heliospheric latitude at a distance from the Sun of about 4 AU. For the past few months magnetic field and plasma data from the spacecraft have indicated that it is in a portion of the heliosphere dominated by the southern polar coronal hole.

C. Solar System Exploration

The major disappointment of the year in space was loss of contact with the United States Mars Observer on 21 August, just as it was being prepared to pressurize its propellant tanks for the 29-minute rocket burn on 24 August that would have injected the spacecraft into an elliptical Mars orbit after an 11-month flight covering 720 million km. The transmitters on the spacecraft were shut down intentionally, to prevent filament damage during the pressurization procedure, but when ground controllers tried to reactivate them 40 minutes later, no signal was received. Multiple efforts to reestablish contact with the spacecraft, based on all the conceivable scenarios

for the failure, were unsuccessful. It was the first post-launch failure of a United States interplanetary or lunar spacecraft since Surveyor 4 on 17 July 1967, but the third failure in a row of Mars-bound spacecraft (the Soviet union's Phobos 1 and 2 failed in 1988 and 1989). An investigation of the failure is still in process, and the impact of the potential $1.01 billion loss on subsequent Russian Federation and United States Mars exploration flights, which had been designed to utilize Mars Observer data, is still being assessed.

Meanwhile, NASA is exploring possible options for reflying Mars Observer's key instruments, spare parts for many of which are still available. Costs for such a mission, which because of Earth-Mars orbital alignment would have to be launched by October 1994 or be delayed until November 1996, are estimated to be $150 million to $200 million (not including launch), far less than the Observer's original cost. The various reflight options almost certainly could not be ready in time for the October 1994 window. They include the use of existing United States military satellite buses, such as that used for the Miniature Sensor Technology Integration (MSTI) spacecraft flown in November 1992 or the 1994 Clementine mission (to observe the Moon and the comet Geographus), and various launchers ranging from Titan-2 or Titan-3 to Proton to the Shuttle.

During 1993 subsystems and scientific instruments for the Russian Federation Mars-94 mission were delivered and integrated at NPO Lavochkin. Launch is scheduled for 24 October 1994. In early December 1992 the Russian Federation decided not to have a third lander on the Mars 94 mission, and invited scientists from the United States to put Oxident experiments, one of which they had planned for that lander, on the other two. The United States experiments are designed to test Martian soil for corrosive materials, to help guide the design of future Mars landers and spacesuits. The original United States plan to also fly a magnetic instrument that would measure the magnetic residue in Martian surface dust was dropped. On 20 January a Russian Federation Marsokhod rover was sent to McDonnell Douglas Aerospace in California for testing, along with seven of the engineers in the Russian Federation who designed and operate it. McDonnell Douglas is evaluating the Marsokhod technology for use in a lunar rover, in cooperation with Moscow's Institute for Space Research, the Babakin Centre of NPO Lavochkin, and VNIITransmash. In one test series from 27 August to 1 September, McDonnell Douglas engineers in California guided a six-wheeled 75 kg Russian Federation-built Mars rover through intricate maneuvers on the slope of an inactive volcano on Siberia's Kamchatka Peninsula, over 5,600 km distant, via an Inmarsat spacecraft.

The United States focus on smaller planetary-exploration spacecraft was intensified by the loss of the Mars Observer. The budget for the Cassini mission to explore Saturn was cut by $250 million, and the Jet Propulsion Laboratory's (JPL) activity intensified on both the Pluto Fast Flyby and the Mars Environmental Survey (MESUR) missions described in last year's report (see document A/AC.105/522). The Miniature Seeker Technology Integration (MSTI-1) spacecraft built for the Ballistic Missile Defense Organization (BMDO) by the USAF Phillips Laboratory demonstrated both the use of "off-the-shelf" instrument technology and streamlined management practices for these smaller, faster missions. In keeping with this philosophy, JPL proposed in January a future series of very small (50 kg), short lifetime (one year) Asteroid, Comet, Moon

Explorer (ACME) spacecraft, to be launched at a rate of about one per year. The joint NASA/BMDO Clementine-1 programme, scheduled for launch in January 1994, also reflects the small, low-cost exploration philosophy. The $50 million spacecraft will study the Moon and the asteroid Geographus while providing sensor data for BMDO. BMDO has also proposed Clementine-2, which would fire military Lightweight Exoatmospheric Projectiles (LEAPs) into two asteroids to study their mineral content, motivated by the need to understand asteroid structures should it become necessary to divert an Earth-approaching asteroid that might be found to be on a collision course with Earth. BMDO estimated that Clementine-2 could be designed and built in two years at a cost of only $35 million, but funds have yet to be approved for the programme.

NASA's new small-satellite Discovery program, which solicited mission concepts costing less than $150 million each, received over 70 suggestions for missions to Mercury, Venus, Mars, Jupiter and its moons, comets, asteroids, and the interplanetary medium, and in January selected 11 for further study. The new NASA focus on smaller, less costly missions has also enabled the agency to introduce a policy that encourages the use of newer, higher-risk technologies and components in its space science program.

This trend in the the United States to smaller missions was echoed by Rene Pellat, the new president of the French space agency on 23 March, when he reiterated NASA Administrator Dan Goldin's emphasis on smaller, less expensive spacecraft in all categories of space activity, and also indicated a strong interest in working more closely with the Russian Federation on both science missions and procurement of Russian technology and systems. Taiwan also focused on small scientific spacecraft, announcing in June its $540 million program to develop three Rocsat satellites. The first of these, Rocsat-1, will be a 400 kg spin-stabilized craft designed to study the solar wind's interaction with the Earth's atmosphere, especially its effects on communications and power transmission in the equatorial region.

NASA's Galileo spacecraft, on its long flight to Jupiter, received its final gravity assist from Earth on 8 December 1992. Efforts to free the spacecraft's main antenna by reorienting the spacecraft to expose the antenna to temperature extremes, by hammering the stuck mechanism repeatedly with its drive motors, and by spinning the spacecraft at high speed continued through March, but were unsuccessful. However, a combination of new software, data compression, and other enhancement techniques have boosted the small low-data-rate antenna's capacity so that Galileo is now expected to achieve about 70 per cent of the mission's original data objectives. Galileo's orbiter will be injected into Jupiter orbit on 7 December 1995, immediately after receiving data from the two atmospheric probes the spacecraft will have released earlier. On 28 August the spacecraft passed asteroid Ida at a distance of 2400 km, taking about 25 photographs, including a five-frame photo mosaic with a resolution of about 35 m taken at a distance of about 3600 km, and other remote-sensing data.

The United States Magellan spacecraft, which has mapped over 98 per cent of Venus's surface since its launch in May 1989, began a 730 orbit aerobraking maneuver on 25 May to reduce its orbit from 8500x170 km to 540x200 km. The maneuver, which decreased Magellan's

apogee by about 10 km per trip around Venus, was completed on 2 August, marking the first successful use of aerobraking for spacecraft orbit transfers. he transfer was accomplished using only about 32 kg of propellant, vs over 900 kg which would have been needed with conventional propulsive braking. Observations of Venus having 200-400 km resolution began from the new orbit on 16 August. Magellan still has 63 kg of propellant, enough to keep the spacecraft operating for about eight more years.

On 11 April Japan's Hiten (formerly Muses-A) spacecraft crash-landed on the Moon as planned, ending a three year study of the effects of gravity on the acceleration and redirection of satellites ("gravity boosting").

D. Search for Extraterrestrial Intelligence (SETI)

In the United States work on NASA's High Resolution Microwave Survey (HRMS), launched in October 1992 after two decades of investment in the system elements, was terminated by Congress on 1 October. Programme managers are currently seeking private financing to continue the survey, since all the instrumentation and other hardware have been built or purchased (at a total cost to date of $58 million) and are available for use.

Considerable work was accomplished prior to the October termination. In one of HRMS's two modes, the Targeted Search, observations made at Arecibo late in 1992 were analyzed, and a planned system upgrade was implemented that will double the system's capacity to process a dual-polarization 20-MHz bandwidth with six simultaneous resolutions as narrow as 1 Hz. These upgrades are needed for the 1994 deployment of the Targeted Search system in Australia.

In the second HRMS mode, the Sky Survey, the new 34 m beam-waveguide antenna at NASA's Goldstone Deep Space Communications complex in California searched about 180 "sky frames," each with an area of 1.4x30 degrees, in a single-polarization 40 MHz bandwidth at X-band. A 26 m antenna also scanned a 5x90° section of the galactic plane at L-band. Work also continued on the Sky Survey operational system, which has 16 times the capability of the current prototype.

A useful byproduct of these SETI observations will be radio astronomical maps of a portion of the galaxy. Both search modes have extraordinary requirements for frequency coverage: 1-10 GHz for the Sky Survey and 1-3 GHz for the Targeted Search; an instantaneous bandwidth of 300 MHz; and a system temperature of 25K. A common design for receivers and feeds is being developed for the two search modes.

Also in the United States, the four million channel SERENDIP III system operated by the University of California at Berkeley entered its second year of observations at Arecibo. The system operates in a commensal mode at 430 MHz, taking advantage of Arecibo's unique feed antenna arrangement to obtain large amounts of observing time. While the primary astronomy observation tracks a position in the sky using a higher-frequency feed, the SERENDIP system rapidly scans another portion of the sky, stepping through the feed's 12 MHz bandwidth three

times every 20 seconds, about the time it takes one part of the sky to move across the beam. The search has already covered 86 per cent of the sky visible to the antenna. Current plans include following up on signals of potential interest that have been detected and developing a new 130 million channel system.

The system for the longest ongoing search, at Ohio State University, is being upgraded to cover the 1.4-1.7 GHz band in a sky survey mode with limited tracking of candidate signals for verification tests. The upgraded system will include a real-time display of the entire spectral region. Several interesting narrowband hydrogen clouds have been discovered and mapped in detail with the current SETI receiver. Plans for future development include installing a copy of the four million channel SERENDIP III system and design of an omnidirectional radio telescope called Argus.

Other activity in the United States includes a high-frequency search at Mt. Wilson for infrared laser signals from 300 nearby stars, in which signals received at 30 THz (10 micron wavelength) are converted to radio frequencies by the heterodyne receiver on one of UC Berkeley's 1.7 m stellar interferometer telescopes and analyzed in a 1,000-channel acoustic-optic spectrometer over a frequency range of 2 GHz (20 km/s).

The META II project in Argentina has nearly completed a second survey of the southern-hemisphere sky at the 1.42 GHz hydrogen line (it complements the META I project at Harvard University in the United States, which surveys the northern hemisphere). Current plans in Argentina include re-observing certain regions, observing nearby stars, and, possibly, sky surveys at different frequencies. Efforts on the Parkes 64 m and Mopra 22 m antennas in Australia continue, as reported last year, in support of the NASA HRMS Targeted Search.

In Europe studies are being conducted of a dual reflector for the focal system of France's Nancay radio telescope to improve its performance significantly, partly for use in SETI observations. NASA and the Nationale Science d'Universite (INSU) are discussing using this telescope for the HRMS Targeted Search during an extended period (e.g., 200 days) later in the decade. As noted in this report last year, Italy is planning to build a 128,000 channel spectrometer for a SETI sky survey in the 408 MHz band at the Northern Cross radiotelescope. This telescope and the Very Long Baseline Interferometer (VLBI) 33 m antenna may also participate in the NASA Targeted Search in the late 1990s.

In the Russian Federation astronomers are continuing to search the Infrared Astronomical Satellite (IRAS) database for evidence of large-scale astro-engineering projects near stars. They also plan to use the 70 m millimeter wave telescope being built in Uzbekistan for SETI observations at the 203-GHz positronium line. SETI plans for the Ratan 600 telescope include observations of stars when they reach opposition to the Sun.

India is building a Giant Meterwave Radiotelescope near Pune. The array of thirty 45 m telescopes will cover frequency bands up to the 1.42 GHz hydrogen line. It is a promising facility for SETI observations because of its sensitivity, sky coverage, and minimal interference

environment.

VI. TECHNOLOGY ADVANCEMENT

A. Propulsion

In the United States, Thiokol completed testing and verification of all engineering requirements for the Castor 120 rocket motor, which will boost Orbital Sciences' launcher and serves as the first stage for Lockheed's LLV family (see above). Data from the final 87 second cold weather test firing, on 4 March, closely matched theoretical predictions. Castor 120 weighs 53,000 kg and produces an average vacuum thrust of 1,630 kN at a specific impulse of 280 seconds.

American Rocket Company (AMROC) conducted three full-scale test firings of its 1.16 MN-rated H-1800 hybrid rocket motor, one on 22 January for 15 seconds, a subsequent 10 second run on 17 February, to demonstrate the hybrid's restart capability, and a third 22 second firing on 3 March, to consume the remaining solid fuel. Average sea-level thrust of the H-1800 development engine (DM-01) was measured at 1.04 MN. AMROC, which has conducted all its operations to date with private sector financing, plans to use three flight-qualified H-1800 motors to launch its four-stage Aquila vehicle late in 1996. Aquila's payload to a 185 km circular orbit will be 907 kg.

The fifth and final development test of the Solid Rocket Motor Upgrade (SRMU) for the United States Titan-4 launcher was successfully completed on 12 September. Production of operational flight-rated motors has been initiated. The Advanced Solid Rocket Motor (ASRM) being developed for the Shuttle did not fare so well; the programme was cancelled by the United States Congress on 1 October.

Rocketdyne demonstrated its revolutionary Simple Low Cost Innovative Pump (SLIC) concept, which consists of only four major parts. It was designed and built at 20 per cent the cost of conventional rocket pumps; uses hydrostatic bearing technology; and will increase reliability and pump life for future expendable and reusable engines.

Energomash of the Russian Federation designed and tested a new derivative of the big 7.5 MN thrust RD-170 four-chamber engine that powers Zenit and Energiya's first stage. The new engine, called the RD-180, uses two RD-170 chambers and a new, smaller pump assembly to deliver about half the RD-170's thrust, which is in the range that warrants serious consideration by companies in the United States for both existing vehicles such as Atlas and proposed new ones such as Spacelifter (see above). Another potential RD-180 application would be in liquid propellant boosters for the Space Shuttle.

In Europe, significant progress was made in propulsion development for the Ariane-5 launch vehicle. The first of eight static tests of its P230 solid rocket booster, the reinforced

structure "Battleship 1" version, took place at Kourou on 10 February, burning as planned for 135 seconds. The first flight version, M1, was tested successfully at Kourou on 25 June. The Vulcain cryogenic stage engine has been run 140 times, with a total of 30,000 seconds of ground testing completed out of a total plan of 80,000. Modifications to solve the combustion instability problems of the L9 storable propellant upper stage were completed and a successful long duration firing was conducted.

Japan successfully tested the LE-7 first-stage cryogenic engine for the H-2, first in a 10 second run on 23 February and conducted a 20 second test on 5 March to evaluate the interaction between the LE-7 and the H-2's first stage. A 100 second run on 31 May and a subsequent full-duration 350 second burn on 15 June were also successful, clearing the way for an H-2 launch in February 1994. A final unscheduled 60 second test was made without incident on 7 July to verify prior data. All LE-7 tests were conducted with the H-2's first stage mated to a complete 38 m dummy launcher. The H-2 will lift 4,000 kg to LEO or 2200 kg to a GTO.

On 6 August the Russian Federation canceled its $400 million contract to sell cryogenic engines and related technology to India, under pressure from the United States. (conformance with the 1987 MTCR was one of the preconditions set by the United States for the previously mentioned 2 September Russian Federation-United States. space station cooperation agreement). India is currently considering whether or not to develop its own cryogenic rocket technology for the Geostationary Space Launch Vehicle.

On 11 May the United States Air Force announced the termination of its Space Nuclear Thermal Propulsion (SNTP) programme to develop a high thrust-to-weight orbit transfer engine employing particle bed nuclear reactor technology. The last United States programme to develop nuclear thermal propulsion, SNTP was canceled due to budget constraints and lack of a well-defined mission objective.

This year's development activity in liquid propellant apogee engines included the following:

In the United States, Aerojet demonstrated a specific impulse of 321 seconds with their bipropellant 490-N nitrogen tetroxide-monomethyl hydrazine (N2O55-MMH) engine, which is made of rhenium with an oxidation-resistant iridium coating. TRW is developing an advanced version of the 450-N dual-mode N2O5-MMH engine currently flying on several commercial satellites, aimed at a specific impulse of 330 seconds. Thiokol has qualified thrust vector control of its solid propellant Star 48B motor for flight use on the COMET mission. Rocketdyne developed a low-cost, accurate laser-drilling fabrication technique for rocket engine micro-orifice injectors, reducing manufacturing time and cost by a factor of 100 relative to conventional methods.

In Europe, the UK's Royal Ordnance demonstrated a specific impulse of 318.5 seconds with their 500-N LEROS-1 N2O5-MMH dual-mode engine, which has a columbium chamber with an oxidation-resistant disilicide coating. Germany's DASA demonstrated a specific impulse

of 316 seconds with the 400-N Mark II N2O5-MMH engine, which is film and radiation cooled. It is built of stainless steel, with the high temperature regions made from an uncoated platinum-rhodium alloy. Europe has also completed a feasibility study of a pump-fed 20-kN N2O5-MMH Advanced Technology Engine for orbit transfer stages. Specific impulse is predicted to be 345 seconds.

Developments this year in electric propulsion for spacecraft were as follows:

In the United States, the 1.8-kW hydrazine arcjet built by Olin Rocket Research, which doubles the specific impulse obtainable from chemical rocket systems, has been accepted for use in several spacecraft for north-south stationkeeping (NSSK). The first of these to be launched is Telstar-4, scheduled late this year; others include Intelsat-8, Echostar, and Asiasat.

The Russian Federation stationary plasma thrusters (SPTs), which have flown over 50 missions, are being considered by manufacturers of several spacecraft. Fakal's new SPT-100 will be used by the Russian Federation Express communication satellite due for launch at the end of this year, and France's SEP will develop and manufacture the next-generation Aton (SPT-Mk2) designed by MIREA.

The German RIT-10 thruster flown on ESA's Eureca spacecraft, discussed in last year's report, was returned to Earth when Eureca was retrieved by the United States Shuttle Endeavor on 24 June. Although in orbit for 10 months, the thruster operated for only 244 hours due to failure of an overheated power cable.

Other planned electric thruster applications include the Melco-Kaufman type device for Japan's ETS-4 technology demonstrator due for launch in 1994; the UK-10 and German RIT-10 thrusters to be flown on ESA's Artemis mission in 1996; and the forthcoming United States flight test of the Russian Federation Topaz nuclear reactor (see below), for which thruster candidates include SPTs of 10 cm and 16 cm diametre, the UK T5, the Hughes 13 cm ion thruster, and the NASA Lewis/Hughes 30 cm ion thruster. The USAF awarded a contract to McDonnell Douglas Aerospace in February to continue design studies of a solar-electric upper stage for transferring satellites into high orbits.

Work also continued this year on magnetoplasmadynamic (MPD) devices and multi-kilowatt arcjets. A 30-kW class ammonia arcjet, tested in 1992 by Phillips Laboratory in the United States to evaluate its electromagnetic interference characteristics, is scheduled to be flown late in 1995 in the ESEX mission aboard the USAF Argus spacecraft. An 8-kW version is to be flown a year later on the Elite mission.

Solid cryogens are being explored at the Phillips Laboratory in the United States. Boron atoms were isolated in solid hydrogen this year for the first time and the next step will be to implant carbon in solid hydrogen, thereby creating a solid monopropellant with a specific impulse 50 per cent higher than that of liquid oxygen and liquid hydrogen.

Also in the United States, Aerojet has successfully tested an environmentally clean solid rocket propellant using a nitrate oxidizer to replace the conventional ammonium perchlorate. Besides eliminating chlorine from the rocket exhaust, the new propellant offers such benefits as simplified processing, lower cost, reduced manufacturing waste, and less sensitivity to explosions. Europe has also conducted laboratory scale development of a new chlorine-free solid composite propellant using glycidyl azide polymer (GAP), hydrazinium nitroformate (HNF), and aluminum, which generate a specific impulse 10 per cent higher than the best current hydroxyl-terminated polybutadiene (HTPB) composite propellants.

One of the two most critical technical issues to be addressed by the United States hypersonic research effort that will replace the former National Aerospace Plane (NASP) programme (see above) is supersonic combustion ramjet operation in the high-teen Mach number range. The United States is currently seeking budget support for a series of HyFlite tests using surplus military missiles to test scramjet operation in key portions of the flight envelope. The "platelet" manufacturing technology demonstrated this year by Aerojet in its cryogenic modular rocket engine, which demonstrated a thrust-to-weight ratio exceeding 400, is directly applicable to scramjet engine construction.

In February the Indian Space Research Organisation released results of two 15 second test flights at Sriharikota in 1992 of an airbreathing rocket, the ABR-200, which the Vikram Sarabhai Space Centre said reached speeds of Mach 23. The University of Queensland in Australia "flew" a scramjet engine at Mach 7.2 in its Brisbane T4 shock tunnel, which simulates the aerothermodynamics and structural stresses of Earth-orbital speeds.

B. Power

In Japan, a preliminary study by the New Energy and Industrial Technology Development Organization (NEDO) is assessing the Solar Power Satellite (SPS) as a candidate for the nation's new energy research programme, and a working group of the Institute of Space and Astronautical Sciences (ISAS) conducted a basic SPS study (SPS-2000). The International Space Year-Microwave Energy Transmission in Space (ISY-METS) experiment was launched to an altitude of 220 km aboard an S-520-16 sounding rocket on 18 February. In this experiment a phased array semiconductor-based antenna system on a "mother" satellite transmitted energy to two rectenna systems, one built by Japanese scientists, the other by NASA's Center for Space Power at Texas A&M University, aboard a "daughter" satellite deployed from the main payload to a distance of about 19 m. The experiment included investigation of the nonlinear plasma effects caused by transmission of the microwave beam through the space plasma.

In the Ukraine, 850 W and 1500 W photovoltaic power systems for the AUOS-SM and Ocean-O vehicles were successfully launched and operated. These systems use linear, cylindrical, and paraboloidal concentrators. Research has been conducted on expanding system power for these satellites to 10 kW, with transmission by microwave beams. Elements of a 3.5 kW Brayton-cycle space power plant with an efficiency of 25 per cent was developed at the Dniepropetrovsk State University. In the Russian Federation, an investigation of the material and

coating resistance to space radiation effects on optical reflectors, conducted aboard the Mir space station, achieved 1.5 years of endurance on 1 July.

European efforts in developing gallium arsenide (GaAs) photovoltaic arrays focused this year on the deposition of gallium arsenide on germanium wafers, improving the efficiency of the GaAs cells to beyond 20 per cent, developing ultrathin GaAs-on-glass cells, establishing GaAs cell survival after over 60,000 thermal cycles in simulated LEO environments, and verifying GaAs photovoltaic cell operability aboard the microsatellites Healthsat, PoSat, and KidSat. GaAs-on-glass has demonstrated specific power of 155 W/kg and 170 W/m^2 compared to 56 W/kg and 96 W/m^2 for conventional silicon cells.

The United States BMDO's plan to flight test a 6 kWe Russian Federation Topaz-2 nuclear powerplant as a power source for an electrically propelled spacecraft ran into a snag in December 1992, when astronomers became concerned about the effect of the reactor's radiation on operations of 12 scientific spacecraft, including the Compton Gamma Ray Observatory. As a result of this concern and other safety-related issues, the BMDO subsequently raised the planned initial operating orbit of the flight-test spacecraft from 1,600 km to over 5,000 km, reducing interference with lower-orbit observatories to a negligible level and virtually zeroing the probability of inadvertent public exposure to radioactive reactor components. BMDO has requested permission to purchase the last four Topaz-2 reactors in the Russian Federation to support the flight test activity, whose December 1995 launch schedule was postponed indefinitely on 15 June due to budget constraints. The aim of BMDO's Topaz programme is to guide engineers in the United States in the design of a larger thermionic space powerplant able to develop up to 40 kWe. The United States Department of Energy (DOE), meanwhile, announced in its budget message on 8 April the termination of the joint DOE-NASA SP-100 nuclear space power reactor development programme, originally also supported by the Department of Defense, which had limped along for nearly a decade on ever-decreasing budgets. DOE also closed its Office of Space.

C. Automation, Robotics, and Teleoperators

The German experiment ROTEX, launched aboard the D2 Spacelab mission on Space Shuttle Columbia in April, was the first telerobot in space. It demonstrated successfully in orbit many of the key technologies developed on the ground in recent years by the artificial intelligence and robotics community; e.g., remote control from the ground, predictive simulation, local force and torque feedback, automated vision, and both task and path planning. ROTEX demonstrated these technologies by assembling a small structure, operating a bayonet closure, and grasping a free floating multi-faceted sphere.

The mission to lower the eight-legged Dante robot into Antarctica's Mt. Erebus volcanic crater failed due to a cable snag, which subsequently caused the cable to break on 2 January. A suitable replacement could not be installed before weather conditions precluded the operation. Before the failure NASA did, however, manage to demonstrate the use of telepresence principles by transferring the robot's control from Mt. Erebus to the Goddard Space Flight Center in

Greenbelt, Maryland.

In July McDonnell Douglas Aerospace completed development of a robot system called Charlotte to operate experiments on the United States Space Shuttle while the astronauts sleep and to provide video data to scientists on the ground. Testing of Charlotte is expected to be conducted aboard Spacehab in 1994 and the robot may also be used on a space station.

D. Environmental Effects of Spaceflight

Several upper-stage breakups occurred this year, increasing the number of catalogued objects in Earth orbit to about 7,400. However, statistical information developed by the United States Haystack programme implies that there are about 60 times as many objects as catalogued that are large enough to be detected by radar; that is, there are about 400,000 objects in Earth orbit. Analysis of data from the Long Duration Exposure Facility (LDEF) gives strong evidence for debris particles in elliptic orbits, such as the transfer orbits used to launch geostationary satellites. The LDEF's Interplanetary Dust Experiment showed that impacts were not randomly distributed along the orbit but occurred typically in bursts lasting 3-5 minutes.

It was concluded at the First European Space Debris Conference at Darmstadt, Germany in April that cleanup of existing debris is neither technically practical nor economically feasible, but that action must be directed by the international community toward the prevention of debris creation. At that meeting the United States, ESA, and Japan announced two such actions: their launch vehicles now routinely jettison leftover propellant from their upper stages (these residues had been a major cause of debris-creating upper stage explosions); and their obsolete spacecraft are now boosted out of the geostationary orbit into "graveyard" orbits instead of simply leaving them there as debris hazards to newer operational spacecraft, even though the cost of doing so, in lost revenues from a single spacecraft's transponders, could be as high as $20 million. the Russian Federation is still considering the implementation of debris-reduction policies for its launchers and spacecraft.

E. Microgravity Research

The Spacelab D-2 mission flown aboard the United States Space Shuttle Columbia in April included experiments primarily from Germany but also from other European nations and Japan. Experiments conducted on D2 included determination of the diffusion processes in molten salts, metals, glasses, and various solutions; evaluation of Marangoni convection, boiling, and critical point phenomena in the Advanced Fluid Physics module; solidification experiments on nucleation, phase separation, directional solidification, and crystal growth using several different methods; robotics; measurement of microgravity disturbances and their propagation; and operational methodologies such as telesupport of the crew from the ground, reprogramming of experimental parameters, reducing crew workload, and enhancing scientific output.

On 22 November 1992 a Skylark-7 sounding rocket launched the 29th German Texus payload from Sweden's Esrange facility. The 400 kg payload carried biological and materials

science experiments to 230 km altitude, providing six minutes of microgravity conditions.

The international Biocosmos-10 (Bion-10) mission, under the auspices of Moscow's Institute of Biomedical problems, was launched aboard a Russian Federation recoverable capsule on 29 December by a Vostok vehicle from Plesetsk. The payload, which consisted of over 20 experiments by scientists from Europe, the Russian Federation, the United States and other nations, included two rhesus monkeys, seeds, beetles, frogs, fish, and a 40 kg "Biobox" incubator, equipped with a centrifuge to provide variable gravity, built by Deutsche Aerospace's Dornier division. One of the mission's main goals was to determine the sensitivity of bone tissue to gravity. Overheating of the capsule, however, forced its return to Karaganda, Kazakhstan, about 800 km from the target landing site, on 10 January, 2.5 days earlier than planned. The overheating (believed to have been caused by inadequate capacity of the thermal control system), along with failure of three out of four of the external instrument shields to close on reentry, caused loss of some experimental subjects and consequent loss of some data. ESA later contracted for four subsequent microgravity-experiment flights on Russian Federation recoverable capsules at a cost of about $6 million, including two more Biobox flights; a Biopan container which will be mounted on the outside of the capsule to expose the payload to space radiation as well as microgravity; a fluid physics experiment; and a liquid-column experiment.

The United States Consort-6 commercial suborbital flight on 19 February carried seven microgravity experiments aboard a Starfire-1 rocket to 300 km altitude, providing 7-8 minutes of microgravity. The cost of the flight, about $2 million, was covered by the insurers of the previous Consort-5 launch, whose second stage motor shut down prematurely.

F. Space Research Facilities

Europe's Eureca microgravity laboratory's onboard materials and materials processing experiments were shut down in March after successful completion, to enable a solar science mission in cooperation with the April observations by instruments in the ATLAS-2 package aboard the United States shuttle and a subsequent full-sky search for sources of X-rays and gamma-rays, which required spinning the spacecraft.

On 16 November 1992 the Russian Federation announced the availability of six retrieval orbital capsules capable of payloads ranging from about 100 to over 1,500 kg. Over 50 of KB Photon's Resurs capsules have been launched by Soyuz vehicles from Plesetsk since 1979, carrying up to 150 kg payloads of which 30 kg can be returned after three weeks in orbit. KB Photon also makes the Photon capsule, in service since 1989, which carries payloads up to 700 kg from Plesetsk for 16 days in orbit and returns them. KB Photon charges experimenters $15,000 to $25,000 per kg. The company is also developing Nika-T, whose first flight is scheduled in 1995, to carry 1,200 kg payloads for three to six months in orbit. NPO Energiya builds the operational Progress-M, which is used regularly to return up to 150 kg from the Mir space station. Lavochkin Associates is developing a new capsule, Tekos, to return 800 kg after up to two years in orbit (first flight in 1995), and has also secured Russian Federation government approval to use 15 decommissioned SS-20 missiles to orbit microgravity experiments

for several days beginning in 1994. KB Salyut has designed a canister for up to 170 kg with orbital lifetimes up to several years. NPO Machinostroyenia is modifying its Almaz capsule, which has returned nine payloads since 1970, for experimental payloads up to 120 kg.

The Wake Shield Facility designed and developed at the University of Houston's Space Vacuum Epitaxy Center in the United States, to be flown aboard Space Shuttle Discovery late in 1993 or early in 1994, is the first facility to make use of the vacuum available in space, rather than the microgravity environment, to grow defect-free semiconductors. A promising fabrication technique, molecular beam epitaxy, suffers from contamination defects in the limited vacuum conditions that can be sustained on Earth. In the wake of a 3.7 m diametre stainless steel disc towed behind an orbiting spacecraft, however, the effective "pumping speed" provides vacuum conditions orders of magnitude better. The initial experiment involves deploying the wake shield from Discovery's payload bay, remotely controlling beams of gallium and arsene vapor to build crystals on seven heated wafers for two days, and retrieving the shield and the sample crystals. If the experiment proves successful, a Wake Shield Mark 2, launched by an expendable vehicle and left in space indefinitely, could serve as a pilot commercial production facility. The shield and crystals, incidentally, will be retrieved by Sergei Krikalev, one of the two Russian Federation cosmonauts who trained as Shuttle mission specialists this year.

A project that originated in NASA's Small Business Innovative Research Programme in 1983 came to fruition on 29 March when the Small Expendable Deployer System (SEDS) successfully launched a payload from a 20 km tether from a USAF Delta-2 rocket whose primary mission was to launch a GPS satellite. The cable unreeled successfully in 78 minutes, carrying a 23 kg instrument package which measured the speed, tilt, and magnetic force of the tether as it swung down toward the Earth and then after 14 more minutes of measurements the fully extended tether was dropped off to burn up in the atmosphere. The purpose of the test, which cost only $10 million compared to $380 million for last year's unsuccessful Shuttle-launched Tethered Satellite System experiment, was to verify theories of tether dynamics in space.

On 3 May France's Arianespace and Novespace and Westinghouse's space division in the United States began marketing a package service that provides launch and recovery of experiments in the Westar capsule, a commercial version of Westinghouse's COMET capsule. Total cost of a Westar launch and recovery as an auxiliary Ariane payload was estimated at $26 million and Novespace is offering potential Westar customers in Europe a price of $65,000 per kg. The 1,000 kg Westar bus has a recoverable capsule and a service module (which can operate in orbit for over two years), each able to carry a 205 kg payload.

G. Materials and Structures

On 29 April Pratt & Whitney of the United States and the E.O. Paton Welding Institute of the Ukraine announced a new joint venture, the Pratt & Whitney-Paton Research Center in Kiev, Ukraine, to conduct research and development of new aerospace materials. Paton's electron beam vaporization process will be explored as a mechanism for coating rocket and jet engine components to reduce Pratt & Whitney's manufacturing costs and to improve engine performance.

NASA plans to replace the aluminum nose cone of the Space Shuttle's external tank with graphite composite, announced on 7 September, is designed to eliminate the need for spray-on foam insulation, which poses a debris impact hazard to the Orbiters. Production of the new cones will begin about mid-1994. Besides requiring 20 times fewer fasteners and providing better thermal resistance than the old design, the new nose cones weigh about 21 kg less.

VII. EDUCATION

A. Teaching Programmes

The International Space University's (ISU's) Board of Directors on 31 January selected Strasbourg, France for ISU's permanent central campus, over competing bids from finalists Toronto, Canada and Kitakyushu, Japan. The deciding factors included Strasbourg's proposed academic programme, its international environment, and a substantial financial support package, subsidized in part by a grant of $3.6 million from ESA for the academic years 1994 and 1995. The ISU also selected 18 affiliate campuses in 12 countries: Australia, Austria, Belgium, Canada, Italy, China, the Russian Federation, Spain, Sweden, Turkey, the United Kingdom, and the United States.

The Third IAF Annual Seminar on the Future of Space Education, held near Mittweida, Germany, 24-26 May, noted the decreasing emphasis on space exploration and an increasing focus on the environment. Delegates from France, Germany, the Russian Federation, the United Kingdom and the United States suggested that space educators anticipate future trends by establishing new educational relations with industries deeply involved in environmental issues, in particular construction and energy.

The first international mini-rocket space camp was organized this year by the Moscow Aviation Institute and the French Association for Science, Technology, and Youth (ANSTJ). The first session will be held in Moscow during the last two weeks of July 1994. The camp's focus will be on building and launching rockets with a mass of about 1 kg to altitudes up to 1 km, and simulating launch operations from Baikonur, Cape Canaveral, and Kourou.

The annual interactive student educational Jason Project focused this year on using satellite imagery to help students identify the location of an undersea research vehicle exploring underwater volcanic vents and ocean life of the west coast of Mexico. Cray Research, Inc., used one of its supercomputers to create a full-color three-dimensional videotape of the Baja California area from Eosat's Landsat images. The images were transmitted to 700,000 students at 26 locations in Bermuda, Canada, the United Kingdom, and the United States via Turner Broadcasting's satellite network, which also provided a live interactive communications link between the students and the scientists exploring the ocean depths, who used land features of the images to guide them to the most probable vent locations.

The Argentina Association of Space Education (A2E2) was formed at the Second Space

Conference of the Americas in Santiago, Chile, to update space information for teachers of courses in elementary and secondary schools in Spanish language countries.

In Brazil a project titled "Dissemination of Space Technologies to the Student Community," was launched to provide public school access to information on remote sensing and its applications. The project has identified teachers as the main conduit to the students and features visits to the Brazilian National Institute for Space Research (INPE), publication of educational brochures, and an exhibit titled "Society-Environment Relations and Space Activities."

Seventy journalists, professors, and students attended a course, "Brazil and the Space Age," at the University of São Paulo, 19-30 July. Jointly sponsored by INPE and the Centre for Science Communication, the course's goal is to improve the public understanding of space in Brazil.

In Canada, the Algonquin Space Campus opened its second summer session at the Algonquin Space Complex near Toronto in June. Of the 15 one-week sessions, three were for teachers, two for adults, and 10 for students who had completed ninth grade. The fee was $430. Subjects included robotics, physics, astronomy, and model rocket experiments.

The amateur space society of Quebec, ARDAA, opened a summer space camp this year near Montreal. Activities include simulated space missions and launching of experimental payloads on student-built rockets.

Activities in Europe included the 11 May launching of a 154 kg Arsene amateur radio minisatellite as an auxiliary Ariane payload (with the Astra 1C satellite). The payload successfully used its apogee-boost motor to achieve an elliptical orbit with an apogee of 37,000 km and a perigee of 17,500 km. Although one of the satellite's three frequency bands (the VHF band) malfunctioned, the other two operated normally. Arsene was built of spare parts accumulated over 13 years by successive generations of French university students at 30 different schools.

The United Kingdom's National Remote Sensing Centre (NRSC) developed a package of curriculum materials to teach geography to 12-14 year-old students using satellite images of four regions of Europe. The package, called "Satellite Eye over Europe," costs about $30.

Studies were initiated in India to develop a dedicated Gramsat ("village" satellite) for disseminating region specific educational and developmental information to individual linguistic groups and regional entities. To help farmers appreciate and assimilate scientific information into their culture fabric, India has launched a national Integrated Mission for Sustainable Development (IMSD), which includes a vital role for satellite remote sensing.

The introduction of remote sensing technology in the educational curricula of both schools and colleges intensified this year. Training courses in remote sensing were organized for

teachers, and textbooks are being updated to include remote sensing and other space technologies. These efforts supplement studies at all educational levels on satellites, rockets, the solar system, and satellite communications, as well as specialized subjects such as electronics, aerospace technology, propellants and fuels, space astronomy, flight dynamics, and launch-vehicle technology.

The Japan Association of Rocketry (JAR) was reestablished in September to educate and encourage young people through model rocket activities. Supported by the Ministry of Education, JAR programmes feature the design, building, and launching of rockets with guidance by the Institute for Space and Astronautical Science (ISAS). A 1,000-N model rocket was launched in Taiki, Hokkaido in August and used to conduct a successful supersonic parachute deployment test.

A cooperative programme between education and industry programme was initiated in the Ukraine this year. The programme is based at Dniepopetrovsk State University, and involves secondary schools, colleges, the university, and Ukrainian industry design offices and plants. The State University and the Karkhov Aviation Institute also added a new field of specialization, electric propulsion, to their traditional training programme for the rocket and space complex.

In the United States, legislation proposed in Congress, the Technology for Education Act of 1993 (Bill No. S1040), would establish a fund of $338 million to use satellites, other communications technologies, and computer networks to link the nation's elementary and secondary schools together and with schools overseas.

On 31 March the Foundation for Advancements in Science and Education (FASE) broadcast its one-hour television special, "Living and Working in Space," over the United States Public Broadcasting System. The programme used professional actors, including national acting award winners, to promote mathematics and science education by showing how such education helps people adjust to and understand conditions different from those on Earth.

On 15 May the United States Space and Rocket Center in Huntsville, Alabama, initiated operations of a Journey to Jupiter simulator. Besides simulating a flight from Earth to Jupiter, the educational programme also includes preflight briefings on space history. A distinguished participant in the Center's Space Camp the week of 2 August was United States President Bill Clinton's 13 year-old daughter Chelsea.

The Planetary Society in Pasadena, California, sponsored a wide range of space education activities this year; for example, teaching kits with posters, videotapes, and other classroom material, the Marslink curriculum project that was to link classroom students to expected discoveries on Mars by the Mars Observer spacecraft via NASA's Spacelink electronic bulletin board, and a student contest to name microrovers for Mars.

The American Institute of Aeronautics and Astronautics sponsored eight university design competitions and engineering contests and held seven regional student newspaper conferences

whose winners competed for awards at a national student conference.

The National Space Society (NSS) sponsored "NSS Goes to School," featuring school visits all over the world by grassroots activists to stimulate interest in science and mathematics by using the appeal of the space programme. The NSS also co-sponsored the Boy Scouts' Space Exploration Merit Badge booth at the national Boy Scout Jamboree, which was attended by over 30,000 scout, and sponsored a special "Human Spaceflight Day" at the National Science Teachers' Association convention in Kansas City.

The Center for Extreme Ultraviolet Astrophysics (CEUA) in California provided hands-on experience to 36 undergraduate students who participated in a NASA astronomy mission. The CEUA also offered a high school student internship and conducted a teachers' workshop.

Over 40 students from 18 universities in Italy, the United Kingdom and the United States worked both as volunteers and as employees on the JPL Pluto mission. Student groups constructed a full-size mockup of the 165 kg spacecraft, three prototype interstage structures, mission operations data visualization software, and designs for data flow architecture and data compression.

B. Public Awareness

A 1 kg sculpture by Arthur Woods, an American artist living in Switzerland, was launched by Mir and deployed into space on 23 March. The sculpture, named "Cosmic Dancer," was featured in a television broadcast during which the Mir cosmonauts discussed esthetics and life onboard a space station. Mr. Woods paid over $100,000 for the sculpture's preparation and launch and for the TV programme.

An essay contest sponsored by Inmarsat and the United Kingdom's International Institute of Communications (IIC) focused on how mobile satellite television services will change people's lives in the year 2000, especially in rural and less developed areas of the world. Essays of 4,000-6,000 words were due at the IIC on 15 July and the winner received a prize of $1,500 and a trip to Mexico City for the IIC's annual conference.

In October the China Supreme Harmony Travel Service opened a space branch offering visits to China's space launch site and launch control centre at Xichang by tourists. This opportunity was made possible by a government ruling in July which opened the formerly secret facilities. Seven day tours cost $2,000.

VIII. INTERNATIONAL COOPERATION AND SPACE LAW

At the thirty-second session of the Legal Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, held in New York from 22 March-8 April, three substantive issues were discussed: a) the question of the early review and possible revision of the Principles

Relevant to the Use of Nuclear Power Sources in Outer Space (adopted by the General Assembly in its resolution 47/68 of 14 December 1992); b) matters relating to the definition and delimitation of outer space and to the character and utilization of the geostationary orbit, including consideration of ways and means to ensure the rational and equitable use of the geostationary orbit without prejudice to the role of the International Telecommunication Union; and c) consideration of the legal aspects related to the application of the principle that the exploration and utilization of outer space should be carried out for the benefit and in the interests of all States, taking into particular account the needs of developing countries.

The Subcommittee did not take any definitive action to revise the Principles on Nuclear Power Sources but did agree that future revision of the substantive scientific and technical provisions of the Principles should be based on developments in these areas and that it was advisable to await input from the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space.

On 10 March, the Russian Federation and the French company Aerospatiale signed a joint space research agreement. Potential joint technology development projects could include the European space plane and studies on hypersonic technology. On 21 May, Canada and the Russian Federation signed an agreement to fly a Canadian cosmonaut aboard the Mir Space Station.

On 2 July, South Africa passed the Space Affairs Act and the Non-Proliferation of Weapons of Mass Destruction Act. The former provides for the establishment of a Council to manage and control certain space affairs, determines its objectives and functions, and describes the manner in which it is to be managed and controlled. The objective on the Non-Proliferation Act is to provide control over weapons of mass destruction and to establish a Council to control and manage matters relating to the proliferation of such weapons in South Africa.

In July, for the first time ever, the legal question of geostationary orbit slot ownership arose. Rimsat, licensed by Tongasat of the Pacific island nation Tonga (which was granted use of several slots by the ITU), moved its Gorizont satellite into the slot at 134° east longitude, already occupied by a Palapa spacecraft belonging to Indonesia's Pacific Satelit Nusantara. Subsequently two satellite operators in the United States, PanAmSat and Columbia Communications Corporation, filed petitions with the United States FCC to take action against Tongasat for alleged slot use abuse. The case is still pending.

Between 15 and 17 July, the United States and the Russia Federation entered into three separate agreements. The first covers commercial launches, from the Russian Federation, of satellites built in the United States or containing components made in the United States. The second relates to space shuttle and space station cooperation, and the third, which deals with curbing the proliferation of missile technology, stipulates that the Russian Federation will comply with the provisions of the Missile Technology Control Regime (MTCR).

The former Soviet republic of Armenia signed up with Intelsat on 14 July, purchasing the

minimum 0.05 per cent share for about $1 million. Micronesia and Bahrain also joined Intelsat in September with minimum shares, bringing the total membership to 128. Bangladesh, Brunei Darussalam, Georgia and the Slovak Republic joined Inmarsat bringing the membership of the organization to 71.

After a 20 year lawsuit, a United States Federal Claims Court ruled on 16 August that the United States government had infringed on a 1959 Hughes patent of a single-jet attitude control system for geostationary satellites, and that 84 spacecraft built by other companies from 1963 to 1982 which used the system were subject to licensing fees. Hughes is seeking 15 per cent of the $3.6-$4 billion cost of the satellites but the United States says the fees should be 1 per cent.

On 20 August the Russian Federation's parliament passed a law defining the roles of the Russian Space Agency and the Russian Space Foundation in science, communications, navigation, and remote sensing. The purpose of the law is to ensure the legal regulation of space activities and promote the potential of space research in industry. It bans orbiting nuclear weapons, use of the Moon for military purposes, and deliberate pollution of space.

In September Intelsat and the United States company Martin Marietta settled a lawsuit stemming from a Titan-3's failure to launch Intelsat 603 into its proper orbit in March 1990, which was found to be caused by the miswiring of the Titan's payload deployer. The settlement terms included a discount price for Intelsat's purchase of additional Intelsat-8 spacecraft from Martin Marietta, whose acquisition of GE Astro Space included a contract for two Intelsat-8 satellites at a cost of $165 million.

Under a settlement reached on 4 October with the United States Justice Department, the Perkin Elmer Corporation, builder of the flawed Hubble Telescope mirror, reimbursed NASA $15 million, about one-tenth the cost NASA incurred to correct the defect.

On 13 October, the Russian Federation and Japan signed an agreement for space cooperation. The agreement primarily establishes a framework for additional cooperation between the two countries. The terms of the agreement provide for the establishment of a "Japan-Russia Joint Committee for Cooperation in Space".

Numerous other bilateral and multi-lateral agreements to conduct cooperative space activities, including those among developed and developing countries and between developing countries themselves, were concluded in 1993. Details of these agreements are contained in sections I-V of this report.

Several important conferences and colloquia dealing with various aspects of space law were held. These included the 36th IISL colloquium on space law, held in conjunction with the 44th IAF Congress, in Graz, Austria, a conference on implementation of the ESA convention, sponsored by the European Centre for Space Law, in Florence, Italy, and an International Conference on Air Transport and Space Applications in a New World, in Tokyo, which was sponsored by the Asian Institute of Air and Space Law.

PART TWO: PROGRESS OF SPACE RESEARCH 1993

I. SPACE STUDIES OF THE EARTH'S SURFACE, METEOROLOGY AND CLIMATE

A. Satellites

In August 1992 the United States and France launched the TOPEX/Poseidon satellite to measure ocean topography. TOPEX/Poseidon uses a radar altimeter to measure sea surface height and in combination with very precise determination of the spacecraft's orbit, the altimetry data will have an accuracy of about 3 cm.

The joint United States-Italian Laser Geodynamics Satellite-II (LAGEOS II), designed to reflect laser beams back to ground stations to precisely measure movements in the Earth's tectonic plates, was launched in October 1992. Long-term, geographically dispersed measurements will reveal how the plates that make up the Earth's crust are moving.

The United States NOAA-13 polar-orbiting satellite was launched in August 1993 and failed to operate shortly afterwards. Consequently, the Solar Backscatter Ultraviolet (SBUV) instrument on NOAA-9 will be activated to provide ozone data and NOAA-11 and NOAA-12 will continue to provide operational sounding and image data.

The French Système pour l'Observation de la Terre (SPOT-3) satellite was launched in September 1993. The satellite provides 10 m resolution and stereo capability to derive elevation information.

In September 1993 the Indian Remote Sensing (IRS-1E) operational weather satellite was placed into the wrong orbit. Similarly, the United States Landsat-6 was launched in October 1993, did not appear in its planned orbit, and its location is unknown. Because satellite trackers have been unable to locate the satellite in any orbit, it has been speculated that the satellite kick motors may have sent it into the ocean rather than to a higher altitude.

The joint French, German and Russian Earth Radiation Budget (ScaRab) instrument is scheduled for launch this autumn on the Russian Meteor-3 series polar-orbiting weather satellite. The launch of a second ScaRab is scheduled for fall 1994. It will provide at least four observations every 24 hours which is necessary for sampling diurnal variations.

India launched INSAT-2A in 1992 and INSAT-2B in 1993. These satellites carry, along with the communication payloads, a Very High Resolution Radiometer (VHRR) payload for meteorological observations and weather forecasting.

Due for launch in November 1993 is the last of the Meteosat Operational Programme, Meteosat-6, equipped with MVIRI.

The United States Atmospheric Laboratory for Applications and Science (ATLAS-1) flew aboard the Space Shuttle Transportation System in March 1992. This was the first in a series of such spacelabs that will study solar output as well as the chemistry and dynamics of the middle atmosphere over a solar cycle of 11 years. Continuing the series, ATLAS-2 was flown in March 1993.

The United States NOAA-J satellite will very likely be called for launch in 1994 because of the failure of NOAA-13. It will be fitted with a Solar Extreme Ultraviolet Monitor (SEM), Solar Backscatter Ultraviolet (SBUV) Monitor and AMSU-B instruments. A new series of NOAA polar-orbiters is scheduled for launch beginning in 1996.

Continuity with the ESA European Remote Sensing-1 (ERS-1) measurements will be provided by ERS-2, scheduled for launch in December 1994. In addition to the ERS-1 instrument suite, the satellite will be equipped with the Global Ocean Monitoring Experiment (GOME), the Along-Track Scanning Radiometer (ATSR)-2 and Precise Range and Range-rate Equipment (PRARE).

Canada will launch its first Earth observation satellite, RADARSAT, in January 1995. It will carry a Synthetic Aperture Radar (SAR) and is designed to provide data for operational applications for five years. Applications include crop monitoring, tropical deforestation, marine activities (including sea state), sea ice distribution and geomorphological information for mineral exploration.

India will launch an operational weather satellite, IRS-P2, in 1994-1995. The satellite will carry a Linear Imaging Self-scanning Sensor (LISS) operating in four spectral bands and a Monocular Electro-optical Stereo Scanner (MEOSS), which is a single optics, single spectral band camera that provides stereoscopic imaging.

India is planning to launch a second-generation Indian Remote Sensing (IRS-1C) satellite in 1995. The IRS-1C will carry a high-resolution panchromatic camera (PAN), LISS, and a coarse-resolution camera (WIFS).

The first in a new series of United States geostationary satellites, the Geostationary Operational Environmental Satellite-I (GOES-I), is scheduled for launch in 1994. The separate imager and sounder instruments will provide concurrent measurements as frequently as every six minutes over selected 1000 km x 1000 km areas and soundings on a full-time basis. The GOES-I imager will operate in five channels. The resolution of the single visible channel will remain at 1 km, while each of the four infrared channels will show at least a twofold improvement. A vastly improved sounding capability will be obtained by increasing the data quantization to 13 bits from the present 10 and by adding six channels for a total of 18. The three-axis stabilized platform will allow the sounder to provide hourly moisture and atmospheric stability, temperature and moisture soundings, and depiction of the boundary layer.

The United States SIR-C and Italian X-band SAR instruments will both fly twice on the Space Shuttle in 1994. The SARs will provide data to interpret geological features, ice processes, and biogeochemical and soil moisture processes. The United States ATLAS-3 and the Measurement of Air Pollution from Satellites (MAPS) are planned to be flown on the Space Shuttle during 1994.

B. Composite Data Sets

Satellite measurements require continuous correlative *in-stiu* data for validation. Also, because satellite-borne instrumentation cannot measure all the important variables, simultaneous in-situ observations are necessary. A selection of interdisciplinary data sets are outlined below.

1. Synthetic Aperture Radar

To assess the utility of SAR data for analysis of ice on the North American Great Lakes, the United States NOAA established a data-set for February 1993, including ERS-1 SAR, Advanced Very High Resolution Radiometer (AVHRR), United States Coast Guard Side Looking Airborne Radar (SLAR), *in-situ* data consisting of ice charts, aerial photographs and video taken from a helicopter, and meteorological data from ground stations and buoys.

Similarly, NASA produced an interdisciplinary data set from the Bonanza Creek Forest Experiment, which includes AIRSAR, SEASAT SAR, and *in-situ* measurements of a wilderness area near Fairbanks, Alaska.

To develop a vegetation canopy model for use in interpretation of forest imagery, Canada has collated data from 1992-1993 at the Petawawa National Forestry Institute near Ottawa. This includes CCD and spectradiometer measurements of the tree canopy, irradiance measurements within the canopy, dielectric measurements of tree components, tree architecture observations, and airborne C-band and X-band SAR measurements.

Canada and ESA obtained a data set (SAREX) consisting of ERS-1 SAR and airborne C-band and X-band SAR measurements and associated surface ground data in Central America, South America and Europe. In preparation for the launch and operation of Canada's RADARSAT satellite, a worldwide airborne campaign of SAR data acquisition, called GLOBESAR 93, is presently underway. Canada also recorded a unique airborne C-band interferometric SAR data-set in the Kananaskis Valley of Alberta in February 1992. Digital terrain models derived from precise traditional surveys were compared with those derived from the interferometric SAR.

2. Upper Atmospheric Research Satellite

The Upper Atmospheric Research Satellite (UARS) was launched by NASA in September 1991. The UARS observatory contains nine instruments that collect data on winds, temperature, atmospheric constituents and energy input into the Earth's atmosphere. NOAA records visible-ultraviolet measurements of the nitrogen dioxide column abundance from a mountain-top

site in Colorado during overpasses of UARS. These data will provide insight into and calibration tests of the satellite data.

The European Arctic Stratospheric Ozone Experiment (EASOE) over the winter of 1991-1992 provided integrated data derived from balloon-borne instruments and from the UARS and showed that ozone depletion is occurring in the Arctic.

3. Satellite Data Reprocessing

The United States Pathfinder data reprocessing programme will create a new generation of Earth-science data sets from previous satellite data by reprocessing them with uniform up-to-date methodologies. The April 1987-November 1988 Phase I period was chosen because it includes field campaigns, spans several growing seasons, and the satellite sensors were all operating correctly. Pathfinder data sets include measurements from the AVHRR, TIROS Operational Vertical Sounder (TOVS), GOES, the Special Sensor Microwave/Imager (SSM/I), the NIMBUS Special Sensor Microwave Radiometer (SSMR), and Landsat Land Cover Change.

Two notable data sets have been produced recently. NOAA has prepared two CD ROMs with data on vegetation, ecosystems, climate, topography, soils and a global vegetation index. A map of the United Kingdom has also been produced using imagery from the Landsat Thematic Mapper that identified 25 distinct landcover classes.

C. Highlights of Scientific Results

1. Middle Atmosphere

One of the major Earth science highlights of 1992 was the discovery that, like the ozone layer over the Antarctic with its well-documented annual depletion, the ozone layer in the Northern Hemisphere is also becoming increasingly vulnerable to depletion. Results from the Second Airborne Arctic Stratospheric Expedition (AASE-II), a six-month study of the atmosphere using the NASA research aircraft and UARS data, revealed that during the winter of 1991-1992 the Northern Hemisphere had a high concentration of ozone-depleting chemicals in the stratosphere, but early warming in late January precluded major ozone depletion. UARS data also revealed that ozone decreases in the mid-latitudes were associated with increased levels of synthetic chlorine and bromine compounds in the stratosphere.

Trajectory calculations in the Northern Hemisphere suggest that ozone-poor air had originated in lower latitudes. Data from UARS showed very low ozone levels in an area extending from about 10°S to about 20°N, roughly coinciding with the densest part of the Mt. Pinatubo volcanic plume, raising the possibility that volcanic eruptions may trigger ozone depletion processes similar to those that occur within the Antarctic ozone hole.

Satellite observations of global distributions of ozone showed that the marked decrease starting in the summer of 1992 had continued into the fall of 1993. SBUV data on the NOAA-11

satellite were among those used to record this record low value. Decreases in total ozone were observed in a large range of latitudes and especially in the Northern Hemisphere mid-latitudes.

Temperature and wind data obtained during the past 20 years from rockets launched by India at Thumba show the presence of quasi-biennial and semi-annual oscillations (QBO and SAO) in the middle atmosphere with large inter-cycle amplitude and phase variations. During the years of easterly QBO phase, SAO amplitudes are lower, and these also happen to be the years of deficient annual rainfall establishing the linkages between tropospheric and middle atmospheric dynamic phenomena.

2. Lower Atmosphere

NOAA implemented a significant improvement to the TOVS and VAS temperature and humidity products on the NOAA polar-orbiting satellites. A surface air temperature parameter instead of a surface temperature parameter is used when computing the first guess. Improvements occurred for cloudy atmospheres near the surface and at higher levels in clear atmospheres. In 1993 NOAA began testing a new VAS Gradient Winds program to produce thermal gradient winds.

ERS-1 SAR imagery with 240 m resolution is used by the United States Navy/NOAA Joint Ice Center in an operational demonstration for ice analysis. Experience indicates that SAR data provides the capability to depict thin ice features and discriminates between multi-year and first-year ice, phenomena not easily observed with the other satellite sensors.

Global observations of cloud properties from satellites are needed to understand the role of the atmospheric constituents in climate change and weather prediction. NOAA has developed remote sensing techniques to provide global measurements of cloud parameters. The TOVS and VAS infrared window and CO_2 absorption band measurements are used to determine an "effective" cloud amount and cloud top pressure. AVHRR data are used to derive total cloud amount and cloud type. A multi-layer cloud amount algorithm will be implemented in 1994. It will determine multiple layers of thin cirrus, low stratus, and deep convective cloud types and their cloud amount and cloud altitude.

NOAA has determined that imagery derived from digital subtraction of two IR window channels is more effective in detecting fog and low clouds at night than single IR channel techniques. Work continues on image processing techniques and the extraction of fog thickness. The same dual IR imagery also has potential applications in the analysis of aircraft icing, precipitation coverage, and the detection of some tropical storm centres.

NOAA is evaluating the utility of Special Sensor Microwave/Imager (SSM/I) observations in short-term forecasting of moisture near the Gulf of Mexico. Aspects of the atmospheric water budget were examined following intense cold air outbreaks over the Gulf of Mexico using operational forecast models, and precipitable water and surface wind speed estimated from the

SSM/I. The observed rate of moistening was often underestimated indicating deficiencies in the inferred magnitude of flux convergence and evaporation.

Mt. Spurr, located 125 km west of Anchorage, Alaska, experienced three major eruptions in 1992, in June, August, and September. As the eruptions were large enough to pose hazards to aircraft, NOAA collected and analyzed all available imagery from the NOAA polar-orbiting satellites and geostationary satellites to determine plume altitude and ash cloud movement. Projected ash cloud trajectories were disseminated to aviation interests. Retrospective data and imagery of the eruptions are available to verify methods of volcano detection using satellite data. In addition to the Mt. Spurr eruptions, similar analyses were made for eruptions of Mt. Bogoslof Russia, Mt. Akutan and Mt. Mageik, Alaska, and Mt. Pinatubo, Philippines.

3. Oceans

Geosat altimeter data showed the variability in sea surface topography off the southern tip of Africa resulting from the interaction of the Agulhas Current with the Antarctic Circumpolar Current. This has been compared with predicted results from the United Kingdom's Fine Resolution Antarctic Model (FRAM), allowing refinement of that model.

The period 1992-93 has been especially exciting for the satellite altimetric community owing to the availability of new data from ERS-1, TOPEX/Poseidon, and declassified data from Geosat (1985-86). By means of computer networks, ERS-1 fast-delivery altimeter data are available to NOAA on a daily basis with a delay of only 3-6 hours. After incorporating a precise orbit and other corrections needed for determination of ocean topography, NOAA retransmits the data to institutions around the world for further analysis. These data are used to monitor sea levels in the tropical Pacific, with particular emphasis on improving El Niño forecasts. NOAA prepares monthly updates of sea level anomaly and publishes these analyses in the NOAA Climate Diagnostics Bulletin.

Advanced onboard tracking systems together with more accurate gravity models have reduced the TOPEX/Poseidon radial orbit error to approximately 5 cm. The data will be used by oceanographers to calibrate the computer models that help forecast future climate changes. Oceanographers observed an equatorial Pacific Kelvin wave, which is a large warm water mass that moves eastward along the equator in the Pacific Ocean and gives rise to El Niño conditions.

Satellite altimetry continues to have an extraordinary impact on the Earth sciences because the sea surface topography measured by radar altimeters can be used to map the gravity field of the Earth. To date, however, only Geosat data have possessed both the accuracy and density of coverage necessary to clearly resolve tectonic details in the marine gravity field on a global basis. The recently declassified Geosat geodetic mission data south of 30°S have had a major impact on marine geophysics and geodesy. As the majority of the world's oceans are located in the Southern Hemisphere, the fine-scale tectonic features of much of the world's gravity field, and hence the sea floor, are viewed for the first time, because the inaccessible Southern Ocean has been only sparsely surveyed by ship. This mapping of the gravity field has resulted in numerous

discoveries about the sea floor and underlying crust. NOAA has computed and distributed this gravity field.

NOAA improved its method of computing AVHRR-based sea surface temperature (SST) for the Global Telecommunications System (GTS) transmissions. In the old method, the first SST retrieval found in a grid element since the last transmission was used. The improved method uses an average of all SST retrievals in the grid element since the last transmission.

The capability of satellite remote sensing to provide synoptic, repetitive and multispectral data has proved to be very useful in the inventory and monitoring of coastal features, such as tidal wetlands, coastal landforms, potential aquaculture sites, mangroves, estuary dynamics/shoreline changes and offshore aspects like suspended sediment dynamics and coastal currents, near-shore bathymetry, and internal waves. Multidate IRS-1A and IRS-1B data have been used to map the entire coastal zone of India on 1:250,000 scale with planimetric and classification accuracies of 90 per cent to 95 per cent. The project has also led to identifying areas undergoing changes in the shoreline. Some examples are: (i) on the Gujarat coast, depositional processes are predominant in the Gulf of Khambhat except in the Mahi estuary; (ii) in Andhra Pradesh, tidal flats and mangroves are reducing in extent because of reclamation; (iii) the Karnataka coast is marked by spectacular spits; and (iv) erosion is noticed north of Madras, while depositional processes prevail at Point Calimere and Nagapattinam.

Through the development of appropriate algorithms, it has been possible to identify various mangrove categories as existing in the Indian coastal zone from multidate satellite data analysis. The dynamics and changes in the mangroves have also been studied to identify the processes related to the same. Such information is being utilized in conservation of the coastal ecosystem and towards ensuring preservation of the biodiversity.

4. Geology of Land Surfaces

Data from the Landsat Thematic Mapper at optical, infrared and radar wavelengths helped scientists from the United States to discover several previously unknown earthquake faults in California's northeastern Mojave Desert. Analysis of the remote sensing images, combined with field observations, indicate that the area is crossed by many young faults.

A relatively new, promising technique for applications in geology, including hazard control, is SAR interferometry. The technique, based on the coherent nature of SAR images, compares the relative phase from two radar images of the same scene. The images may be obtained simultaneously by an aircraft system with two antennas; such a system is operated by NASA as part of the three-frequency polarimetric AIRSAR. In the case of satellites the two images are obtained at separate times from orbits which are closely spaced. In order to achieve coherency the time interval between the image acquisitions preferably should be just a few days because the surface properties should not change significantly between the acquisitions. The main application of SAR interferometry is topographic mapping with high spatial resolution. The feasibility of mapping crustal movements by means of differential interferometry was

demonstrated with ERS-1 SAR data acquired before and after the Landers earthquake in Southern California. The interferogram provides a clear visualization of the movements caused by the earthquake. Potential applications include post-seismic monitoring, erosion monitoring and monitoring terrain movement in volcanic zones. Vertical movements on the order of 1 cm can be detected by differential interferometry. The FRINGE Working Group was established by ESA to develop and demonstrate interferometric SAR techniques based on ERS-1 data.

Various activities on hazard monitoring and reduction have been initiated in response to the United Nations designation of the "Decade of Natural Disaster Reduction" (1990-2000). The United Nations Educational, Scientific and Cultural Organization (UNESCO), the government of the Netherlands and the Commission of the European Communities (CEC) are sponsoring a programme on "Geo Information for Environmentally Sound Management of Natural Resources." Within this programme, among other topics, methodologies for slope instability hazard zonation are being developed using information from high resolution Earth observation satellite sensors such as on SPOT and Landsat. The satellite data were found to be useful for hazard mapping at regional scales, as demonstrated in a pilot project carried out in Colombia.

Data from the Indian remote sensing satellites, IRS-1A and IRS-1B, generated up-to-date maps and statistics on land use and land cover. Using the multidate data, land use and land cover maps for India have been prepared giving details on agricultural lands, forest cover, wastelands, and coastal zones. The corresponding statistics for various land use and land cover classes have been prepared and field verified through random sampling methods. These maps form the basis for agroclimatic zonal planning for improving the productivity of the lands.

5. Land and Ocean Productivity

An information access network for Africa has been developed under ESA to improve early warning of food crisis and natural disasters. It makes use of satellite telecommunications to connect the Rome headquarters of the Food and Agriculture Organization (FAO) with regional offices in Africa. The transmitted data include imagery and derived products from environmental satellites providing information on precipitation and vegetation conditions in Africa. For several years the FAO has been involved in the transfer of remote sensing technology to developing countries to contribute to the solution of problems in various fields such as food security, agricultural productivity, desertification, and tropical forestry.

The Tropical Ecosystem Environment Observations by Satellites (TREES) programme is a joint major project of ESA and CEC to assess and monitor on a long term basis the tropical forests at regional to global scales. During the first phase of the project, which is already completed, AVHRR data were collected and analyzed over the global tropical zone. During the second phase methods are being developed for utilization of SAR data for ecological monitoring of the tropical zone as well as integrated methods based on SAR data and optical imagery. Ongoing investigations are primarily based on ERS-1 SAR data. The final goal of the TREES project is to establish an operational tool for monitoring extent and conditions of tropical forests on a continuous basis.

Significant progress has been made in the understanding of radar backscatter from vegetated surfaces and the development of techniques for the detection of crop type and forest biomass from SAR data. Airborne SAR and scatterometer campaigns, carried out in various test sites in Europe over the 1987-1991 period showed the capabilities of multi-frequency SAR data for crop type discrimination. Though ERS-1 SAR is only a single-channel SAR system, it was found to be useful for separation of crop types if multi-temporal data are used. Interesting results on soil moisture monitoring were obtained with ERS-1 SAR data. The radar backscatter was found to correlate directly with the moisture content of bare soils.

In India, data from IRS-1A and IRS-1B are used in the Crop Acreage and Production Estimation (CAPE) programme. Information on crop acreage and yield estimation is given one to 1 1/2 months in advance of harvest for several purposes such as pricing, movement of grains, and storage. Models have been developed on likely crop yields for different crop regions.

NOAA developed a soil wetness index that uses the difference between the 85-GHz and 19-GHz horizontally polarized data from SSM/I on the United States Air Force Defense Meteorological Satellite Program (DMSP) satellites. The experimental product is extremely useful for monitoring the areal extent of flooding for nearly all weather conditions, excluding actively precipitating areas. This index is also being compared with the Palmer Drought Index and cumulative rainfall.

A NASA study indicated that, while the rate of tropical deforestation is decreasing in the Brazilian Amazon Basin, the overall extent of deforestation and the adverse effects on the topical forest habitat have increased since the late 1970s. Data from the Landsat-4 and Landsat-5 satellites covering 1978-88 indicate that although the extent of deforestation is less than expected, deforestation has increased substantially and created adverse "edge effects" that pose a significant threat to the habitat of plant and animal species. "Edge effects" are the destruction or degradation of natural habitats that occur on the fringes of deforested areas.

The United Kingdom's Terrestrial Initiative in Global Environmental Research (TIGER) programme is examining carbon fluxes in tropical forests with field campaigns in Brazil. This involves the use of simultaneous use of AVHRR and SAR to evaluate spatial extent of different regeneration states coupled with *in-situ* measurements of CO_2 exchange to predict the contribution made by tropical forests on a global scale. These studies complement the Boreal Ecosystems-Atmosphere Study (BOREAS), in which the United Kingdom is involved in the modeling of CO_2 exchange in boreal forests of Canada through coupling of remotely sensed data to ecosystem simulation models.

NASA has constructed a 7 1/2 year time series of global algae biomass from NIMBUS-7 Coastal Zone Color Scanner (CZCS) data. Large interannual variability occurs in oceanic biomass and blooms in the equatorial oceans can be larger than expected and play an important role in controlling degassing of CO_2. The discharge of the Amazon River is carried at least 75 per cent of the way towards Africa in the Atlantic Ocean, while the Orinoco River plume dominates the surface variability in the Caribbean Sea. Improved models of regional primary

production are based on satellite-derived algae biomass, sea surface temperature, and historical data on photoplankton physiology.

NASA conducted a series of aircraft flights in August and September 1992 in the equatorial Pacific as part of the Joint Global Ocean Flux Study (JGOFS). An unexpectedly high productivity of microscopic plants occurred near the equator in the Pacific Ocean. Airborne data were linked with observations from the Space Shuttle to guide research vessels to areas of high productivity.

IRS-1A and IRS-1B data in the broad spectral bands of blue, green and red regions have indicated the detection of high chlorophyll concentrations and associated high productivity.

6. Pollution Monitoring

Oil spills continue to be monitored with airborne and satellite instrumentation. The United Kingdom flew an airborne imaging spectrometer to monitor oil spills from the tanker Braer in the Shetlands. ERS-1 SAR imagery has indicated its value in detecting and monitoring oil spills.

NOAA uses AVHRR data to observe aerosol optical thickness (AOT) over the oceans. The AOT is derived from cloud-free intensity measurements of reflected solar radiation compared with radiative transfer model results. This product has been particularly useful in monitoring the evolution of the aerosol layers generated by the eruptions of Mt. Pinatubo and Mt. Hudson in 1991.

Global air temperature data obtained from TOVS and Microwave Sounding Unit (MSU) quantified the extensive cooling effects of stratospheric aerosols produced by the 1991 eruption of Mt. Pinatubo. Incident solar radiation is reflected back to space by stratospheric aerosols. The loss of the warming solar radiation exceeds the smaller amount of infrared radiation trapped by the aerosols, hence resulting in a temporary cooling of the Earth.

7. Glaciology

Spaceborne observations are particularly important at the Poles, where information is difficult to acquire. Many countries are involved in national and international investigations of ice sheet dynamics. Radar altimeter data are providing precise repetitive measurements of Antarctic ice sheets, which will ultimately resolve their state of flux. Measurements by the Geosat altimeter have revealed surface flow features and reflected underlying topography of the Antarctic landmass; ERS-1 data is providing even better coverage. The International Polar Ice Sheet Program, involving 23 countries in the largest ever comprehensive study of the polar ice sheets, uses altimeter, SAR and ATSR data to measure all elements of the mass-balance equation.

D. Contributions to International Programmes

Coordination of global change research is achieved on a global scale through both formal and informal mechanisms. A number of the key United States global change research programmes are coordinated with their counterpart programs in other countries through three major multilateral programmes: the World Climate Research Programme (WCRP); the International Geosphere- Biosphere Programme (IGBP) and the Human Dimensions of Global Environmental Change Programme (HDP). These programmes are conducted under the aegis of United Nations specialized agencies (e.g., World Meteorological Organization and United Nations Environment Programme), UNESCO's Intergovernmental Oceanographic Commission (IOC), and the non-governmental International Council of Scientific Unions (ICSU). Satellite data are used in all global change investigations. Three examples are described below.

The Global Energy and Water Cycle Experiment (GEWEX), a core activity of the WCRP, seeks to improve our understanding and prediction of changes in water recourses arising from climate change. Canada's activity will concentrate on the Mackenzie Basin and will utilize data from SSM/I, AVHRR and Landsat.

The Joint Global Ocean Flux Study (JGOFS), a core project of the IGBP, seeks to understand the relationship between ocean biology and carbon dioxide and to develop a capacity to predict how these processes will react and contribute to climate change. Data from the polar-orbiting Sea-viewing Wide Field Sensor (SeaWIFS) spacecraft, which is scheduled for launch in 1994, is important to JGOFS investigators because it will provide a global picture by removing the temporal and spatial variability of *in-situ* measurements.

The aforementioned BOREAS programme is a joint activity of the United States and Canada, and is an activity of the International Satellite Cloud Climatology Project (ISLSCP) and related to the IGBP. BOREAS seeks to improve our understanding, and provide tools for forecasting how the boreal forest and the climate system interact. Remotely sensed data from AVHRR, Landsat Thematic Mapper and MSS, ERS-1, Japanese Earth Remote Sensing-1 satellite (JERS-1) and SPOT will be used.

National agencies with responsibility for space-based Earth observation programmes that support global change research coordinate these programs with those of other countries through the informal international Committee on Earth Observations Satellites (CEOS). In December 1992, CEOS approved an updated data policy that aims to provide satellite data from all missions to global change research scientists for the cost of fulfilling the users' requests.

The CEOS Working Group on Data (WGD) now has four technical subgroups to address specific issues in detail: Data Product Format; Catalogue; Network; and Auxiliary Data. The WGD Data Product Format Subgroup has developed standard data formats and member agencies have agreed to incorporate them into ongoing data management planning. To further such coordination, a library of accepted formats is maintained. The Catalogue Subgroup (CS) coordinated the development of the CEOS International Directory Network with Coordinating

Nodes in the Western Hemisphere, Asia, and Europe, and drafted a document which presents guidelines and recommendations by the CS in developing internationally interoperable catalogue systems. The Network Subgroup is addressing issues of user-to-user communication using ground-based networking to deliver a variety of data, including catalogue (Directory, Guide, and Inventory) information, browse,and quick look imagery, as well as raw data sets or derived data sets. The Auxiliary Data Subgroup, formed in October 1992, will focus primarily on auxiliary data sets in the framework of Earth observations, stressing interaction with CEOS affiliates in special fields of global change research.

E. Public Education and Awareness

One of the major themes of the International Space Year (ISY) 1992 was education. An example of an education and public awareness activity is Canada's interactive Global Change Encyclopedia (GEOSCOPE), portraying the contribution that remote sensing from space can make to the monitoring of global environmental change on Earth. The GEOSCOPE project demonstrates to a large number of people around the world, through hands-on experience, that satellite data are of vital importance in monitoring the global environment. The project is also intended to illustrate the profound changes occurring in many parts of the world. The data are available on two CD-ROM optical disks.

F. Summary

Concerns about the global environment know no national boundary as demonstrated by the abundant international cooperation and goodwill of those involved in collection, distribution and analysis of data from space-based instruments. Progress in climate research depends on the availability of a variety of geophysical data sets to describe the boundary conditions and forcing functions of the climate system. The unique perspective from space provides the opportunity for observations well suited for studies of the Earth's atmosphere, land and ocean, which are essential components of the climatic system and which remain severely undersampled. Although both satellite-based and ground-based recording systems provide essential information for global climate studies, satellite-borne instrumentation yields unprecedented spatial and temporal coverage of the global ocean.

II. SPACE STUDIES OF THE EARTH-MOON SYSTEM, PLANETS AND SMALL BODIES OF THE SOLAR SYSTEM

A. The Terrestrial Planets

1. Venus

NASA's Magellan spacecraft has completed three radar mapping cycles, bringing the image coverage to 98 per cent of the planet's surface and also finished the fourth cycle, for gravity field measurements, from the original elliptical orbit. The spacecraft then successfully

used areobraking to make the orbit low and circular. Magellan is now making the gravity field measurements from this new orbit. The imagery, together with data on altimetry and radio-physical properties of the surface, are now under investigation by many science teams with broad international cooperation. Some highlights of the analyses so far undertaken are summarized below:

(i) Among about 1,000 impact craters identified on the surface of Venus, the majority look pristine with ejecta not embayed by lavas from the surrounding volcanic plains. The spatial distribution of the craters is indistinguishable from a random one. This can be interpreted as an indication that about 500 million years ago Venus experienced intense, global volcanic and tectonic resurfacing which was followed by only minor endogenic activity.

(ii) The continuing photogeologic studies confirmed early interpretations suggesting that Venus has no plate tectonics. This generates the question why this planet, which is so close to Earth in mass and size, implying close similarity in bulk composition as well, is so different from Earth in the style of its endogenic activity.

(iii) The Magellan imagery discovered examples of aeolian transport on Venus, mostly in the form of wind streaks and in a few phases in the form of dunes. But despite these obvious indications of weathering, the average rate of resurfacing on Venus is strikingly low (a few millimetres per million years) in agreement with earlier estimates based on the results of the Venera-15 and Venera-16 missions.

2. Moon

The Galileo flyby on the Moon in December 1992 was very successful, obtaining new data on the lunar highlands and their mineralic composition near the North Pole. The Clementine Mission to study the Moon and the asteroid Geographos is in progress. This mission, which will use technology from the United Statees Department of Defense, is planned to be launched by NASA in January 1994.

3. Mars

NASA's Mars Observer (MO) spacecraft, which was launched on 25 September 1992, stopped communicating with Earth in August 1993. This failure occurred four days before orbit insertion around Mars during a procedure of fuel tank pressurization. NASA is now considering various options to meet the goals of the MO programme with another spacecraft, including possible launch of the spare spacecraft to Mars in October 1994. The Russian international Mars-94 mission which is planned to be launched in October 1994 from Baikonur, Khazakstan, is planned to bring a spacecraft into an elliptical orbit with a period of about 14 hours. This orbit may be changed for better communication with the landers because the MO relay is now not available. Mars-94 will carry a multiple-experiment payload, and will observe the Martian surface, atmosphere and plasma environment. In addition, it will place two penetrators and two small stations on the Martian surface for long-term scientific observations.

B. The Outer Planets

1. Jupiter

The Galileo spacecraft, launched by NASA in October 1989, completed its last required gravity-assist maneuver with a flyby of the Earth-Moon system in December 1992. The spacecraft made a successful reconnaissance flyby of the asteroid Ida in August 1993 and is now on track for its encounter with the Jupiter system in December 1995. All attempts to open the high-gain antenna have failed, and it is a last hope that the orbit insertion burn will accomplish what many dedicated efforts have failed to do. Failure will not ruin the mission, however, since reprogramming has ensured that about 7 per cent of the proposed observations can be carried out and the data returned to Earth with the low-gain antenna.

2. Saturn

The NASA-ESA Cassini-Huygens mission is being developed following the new guidelines developed two years ago in response to budgetary pressures. The project is on schedule for a launch in October 1997, with arrival in the Saturn system scheduled for 2004.

C. Small Bodies in the Solar System

1. Asteroids

The Galileo flyby of Ida in August 1993 was successful, but the loss of the spacecraft's high-gain antenna meant that even the first image was not fully returned to Earth until late September 1993. The full data set is not expected to be available until the spring of 1994.

2. Comets

A new version of the original ESA-NASA Comet Sample Return Mission called ROSETTA has been selected by ESA as its Third Cornerstone mission. The new version of ROSETTA as an ESA-alone mission will be a comet rendezvous with orbiter and with *in-situ* probing from a lander.

3. Dust

New data on interplanetary and near-Earth dust became available from the Galileo and Ulysses spacecraft and from the ESA-Giotto and Japanese Hiten spaceprobes. Analyses of NASA's Long Duration Exposure Facility (LDEF), which was retrieved in 1990 after six years in space are still revealing new information on interplanetary meteoroids and man-made space debris. Interplanetary dust measurements from the Galileo and Ulysses spacecraft covering the heliocentric distance from 0.7 to 5.4 AU demonstrate that zodiacal dust inside about 3 AU orbits the Sun on low eccentric, low inclination orbits. No enhanced dust flux was recorded during Galileo's flybys of the asteroids Gaspra and Ida. At the distance of Jupiter periodic dust streams

originating from the Jovian system and interstellar dust have been discovered from the Ulysses dust detector. Interstellar dust grains are identified by their retrograde trajectories and hyperbolic speeds at the position of Ulysses. Dust from volcanoes on Io and the Jovian dust ring are proposed mechanisms for the generation of the Ulysses dust streams. Giotto's flyby on comet Grigg-Skjellerup in 1992 showed that this comet is much less dusty than comet Halley. The Japanese satellite Hiten was launched in 1990 and reached a maximum distance of 1.5 million km from the Earth. After three years in orbit it crashed on the Moon in April 1993. The MDC instrument onboard monitored successfully the dust environment of the Earth-Moon system and in interplanetary space.

An important question of the analyses of samples retrieved from LDEF is the separation of natural meteoroids from space debris. This is done both by studying the impact flux directions and by chemical analysis of residues in impact craters. Both methods show that debris dominates the micron sized particles in low-Earth-orbits. Progress has been made in analysis and theory of interplanetary dust particles (IDP's) collected in the stratosphere. Significant enrichments in volatile elements if compared to CI chondrites have been found. This observation is being used for the argument that these particles consist of very primitive solar system material that had never seen temperatures above 500° C.

III. SPACE STUDIES OF THE UPPER ATMOSPHERES OF THE EARTH AND PLANETS, INCLUDING REFERENCE ATMOSPHERES

A. The Earth's Middle Atmosphere

The middle atmosphere is a very active topic for research with numerous groups from around the world involved. Various techniques of measurement are employed, such as ground-based monitoring, *in situ* sounding by rockets and satellite remote sensing. The experiments are accompanied by modelling activities and by theoretical studies of individual processes. In this section, some examples of the activities in 1993 are presented. Occasionally, efforts are coordinated as "campaigns", where measurements are performed (more or less) simultaneously from one or more stations.

Experimental and theoretical attempts to understand (polar mesosphere summer echoes (PMSEs), that is the strong radar echoes received from around the mesopause at northern latitudes in summer, continued in 1993. During the SCALE campaign in July and August 1993 *in situ* measurements of neutral and plasma fluctuations were performed simultaneously with European Incoherent Scatter (EISCAT) VHF radar observations of PMSE from northern Norway. Strong PMSE were occasionally observed around 85 km (every other day or so). The *in situ* instruments showed strong features in the plasma density at approximately the same height. Together with the neutral density fluctuations these observations will provide further insight into this intriguing phenomenon.

In mid-January to mid-February 1993 a mobile VHF radar system was installed in the southern hemisphere (62°S). Unexpectedly, no PMSE were observed in the entire period. This is tentatively explained by the assumption that the mean upper mesospheric temperature is higher in the southern hemisphere compared to northern latitudes, prohibiting the formation of cluster particles which are believed to be associated with PMSE.

Another phenomenon which also occurs only in the summer mesopause region at high latitudes, namely noctilucent clouds (NLC), is also associated with large particles and is therefore most likely related to PMSE (a strong correlation is not expected, however, since rather different observation conditions are required). Coordinated with SCALE, a campaign called NLC-93 took place in northern Sweden in order to study noctilucent clouds. In addition, a Rayleigh lidar observed NLC from the ground at Andoya, in northern Norway, and UARS detected NLC using optical instruments. The first results of these measurements are expected in the near future.

Remote sensing from the ground by lidars and radars is still a very active part of middle atmosphere research. Emphasis is put on the understanding of the creation mechanism and the morphology of gravity waves, which are known to play a crucial role in the middle atmosphere, but which are mainly generated in the troposphere and middle atmosphere. Numerous international groups work on this topic.

The first results obtained from UARS, launched in August 1991, and accompanying ground-based measurements are now available in the literature. The instruments on UARS measure the most important constituents of the stratosphere and mesosphere, as well as temperatures and winds. The validation of onboard experiments shows that the data are reliable in general. UARS measurements provide the first global maps of many minor constituents such as CO, CH_4, N_2O, CCl_2F_2(Fl_2), and of mesospheric winds. The first UARS results confirm the close coincidence between ozone decrease and the CO increase in the polar vortex. The UARS data also show an increase of mesospheric CO with polar latitudes in winter and its increase with altitude in the upper mesosphere.

The primary data taking phase of UARS concluded during 1993, although several of the instruments are continuing to operate. The data collected gives a detailed picture of the dynamics, thermal structure, composition and solar inputs to the middle atmosphere which is now being used to address questions related to middle atmosphere variability and ozone depletion. In addition to the chemical budgets and polar vortex evolution studies which were primary goals from the outset, the UARS observations are proving invaluable for the study of heterogeneous processes through the simultaneous observation of Polar Stratospheric Clouds and the sulfuric aerosol cloud from Mt Pinatubo.

The UARS data set was released for general use by the scientific community at large in September 1993 and is expected to be a valuable resource for many years to come.

The Mt. Pinatubo volcanic eruption in June 1991 and its associated deposition of extremely large amounts of volcanic aerosols showed large impact on the middle atmosphere,

especially in the stratosphere. The volcanic aerosols "spoilt" the whole lower half of the stratosphere on global scales including polar regions. The decline of aerosols is very slow. They induced a decrease of global surface temperature, a significant decrease of total ozone at low latitudes and some decrease of total ozone at middle latitudes. In addition, strong circulation perturbations, which contribute to short-time extreme decreases of total ozone at higher middle latitudes, may probably be related to Mt. Pinatubo as well. A jump of OH mesospheric temperatures near 86 km above Wuppertal (Germany) by +10 K, which persists until now, is considered to be a consequence of Mt. Pinatubo eruption. The whole middle atmosphere appears to be considerably disturbed by the Mt. Pinatubo eruption. Expected lifetime of this disturbance is several years.

The energy budget of the middle atmosphere has gained further interest in 1993 since it is known that some of the fundamental contributions may be very different from what was believed earlier. For example, *in situ* measurements of fine scale structures with unprecedented resolution have shown that the effect of heating by turbulent energy dissipation on the energy budget of the upper atmosphere is significantly smaller than commonly stated in the literature. This result will have some impact on the modelling of the upper atmosphere. Other fundamental processes important for the energy budget of the middle atmosphere, e.g. the release of chemical energy or the excitation of carbon dioxide by atomic oxygen, have been further investigated by means of models which are supported by observations, e.g. from UARS.

The coupling mechanisms between the middle atmosphere and the layers above and below have been studied both by numerical experiments and by remote sounding (mainly radars and lidars). The efforts have been coordinated worldwide in programs such as Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR), Upward Coupling of Wave Energy (UCWE) or Mesosphere, Lower Thermosphere Coupling Study (MLTCS).

The middle atmosphere at equatorial latitudes is being studied in autumn 1993 in a campaign called Coupling and Dynamics in Regions Equatorial (CADRE). Both ground-based and *in situ* techniques are being employed.

B. The Earth's Upper Atmosphere and Ionosphere

During the period under review there have been a relatively small number of national and international research rockets and satellites dedicated to the study of the thermosphere and ionosphere.

Following the success of the Swedish Viking satellite, Sweden, in collaboration with Germany, launched the Freja satellite in October 1992. The satellite was launched "piggy-back" on a Long March 2 Rocket from the Juiquan Satellite Centre in China. Freja weighs 259 kg and was successfully placed in a lower orbit than Viking, i.e., in the lower part of the region where there is an interchange or interaction between the magnetosphere and ionosphere. The orbit ranges between 600 km and 1720 km, with an inclination of 63°.

The scientific mission of Freja has many similarities with that of Viking. The auroral zone is thus the mission target and the satellite will make high resolution measurements in the upper ionosphere and lower magnetosphere. The Freja design yields substantially higher data rates than those available for Viking. Freja will be operated during a period of intense solar activity, whereas Viking carried out its mission during a period of low solar activity. This provides opportunities for extremely useful comparisons.

In the field of auroral and ionospheric physics, the Pulsaur rocket project is being developed by scientists from Norway and the United States to study the ionosphere during a pulsating auroral event. Launch is expected in early 1994.

Individual instruments have been flown on a number of spacecraft dedicated to other primary purposes. Examples include the Space Environment Monitors on the NOAA TIROS spacecraft which define and routinely monitor the energetic particle fluxes incident on the upper atmosphere. Future NOAA TIROS spacecraft will also carry the Remote Atmospheric and Ionospheric Detection System (RAIDS), which will monitor the density distribution of thermospheric and ionospheric species by means of limb scanning from a high-inclination orbit near 800 km altitude. The United States DMSP spacecraft will also carry instruments which measure ion drifts and field aligned currents, in addition to the energetic particle precipitation incident on the upper atmosphere. The exploitation of data from these and other orbital instruments (including instruments on spacecraft devoted primarily to magnetospheric or plasma physics research), in combination with data from networks of ground-based instruments, have made it possible to carry out a series of cooperative programs for studying solar and geomagnetic activity conditions.

The primary measurements of solar and magnetospheric energy inputs to the thermosphere and ionosphere can also be used to define the inputs to global numerical models. Such models can now provide near real-time computations of the overall qualitative response of the thermosphere and ionosphere. Obtaining indices related to solar and geomagnetic activity, which faithfully reproduce the highly detailed and time-dependent patterns of auroral precipitation and plasma convection, remains a problem. There are no space missions planned for investigating one of the critical outstanding issues -- the global measurement of mesospheric, thermospheric and ionospheric dynamics. These interrelated motions control many aspects of the chemical and energetic behavior of the upper atmosphere and ionosphere. The current state of knowledge is dependent on a highly fragmentary data base and numerical models. Due to the shortage of real observational data, these numerical models have unfortunately never been validated.

The global electric circuit is largely driven by the external magnetospheric convective field at high latitudes and by the global E-region dynamo with an internal source, mainly thunderstorm-generated fields in the lower atmosphere. Investigations of the global but unexpectedly large middle-atmosphere electric fields.

UARS continues to provide valuable data on the lower atmosphere. The Solar Terrestrial Energy Programme (STEP) is planning and implementing a number of programmes within the

field of ionosphere, thermosphere and middle atmosphere physics. It should be stressed that long-term ground-based observations will play a key role in the study of the climatology of the space environment.

Some progress has been made in modelling long-term changes in ionospheric variability. The combination of ground-based and space observations is particularly important in the development of the International Reference Ionosphere (IRI).

The Occultation Radiometer (ORA) on the European Retrievable Carrier (EURECA) was returned to Earth in July after about a year of observing water vapour and aerosols in the upper atmosphere. The data are now being analyzed to understand better the processes of water vapour destruction and loss in the upper stratosphere and mesosphere.

C. Planetary Atmospheres and Aeronomy

The Pioneer-Venus Orbiter spacecraft has successfully investigated the atmosphere of Venus for 14 years. This is a record in the history of space studies of planetary atmospheres. A full solar cycle of the behaviour of the Venusian ionosphere was documented, yielding a better understanding of its nature, including the mechanism of night-time ionization, winds in the upper atmosphere, etc.

A new set of data about the Venusian atmosphere will eventually be provided by the entry of the spacecraft into the atmosphere as a result of the natural evolution of its orbit.

Multispectral imaging of the nightside of Venus in the near infrared during the Galileo encounter in February 1990 has been analyzed and revealed the deep cloud structure in unprecedented detail.

The deuterium/hydrogen abundance ratio is approximately 100 times larger on Venus than on Earth. This was recognized early by indirect analysis of the mass spectrometer of the Pioneer-Venus large probe data and has recently been confirmed by ground-based measurements. The deuterium enrichment can be explained by the removal of most of the water from Venus in the early stages of its evolution. It is also expected that the drag and torque on the Magellan spacecraft will provide important information on the atmospheric structure of Venus.

The Galileo observations of the Venusian atmosphere obtained as a bonus after the mission to Jupiter was re-targeted via Venus, have yielded a rich harvest of interesting results, some of which appeared in a special issue of Planetary and Space Science in 1993. The dynamics and meteorology of the hitherto unmapped lower atmosphere are among the topics addressed. Surface features and an asymmetric distribution of carbon monoxide between the hemispheres are visible in the near infrared maps.

A comparison of the results of studies of aerosols in the atmosphere of Mars made by the Viking and Phobos 2 missions showed that the global dust content probably has a time scale of approximately 10 years with a reduction of a factor of three (at least for the spring season).

Analysis of another set of Phobos mission data (solar occultation spectrometry) led to the tentative identification of formaldehyde as a trace constituent in the atmosphere of Mars (abundance of about 0.0000001). The presence of this gas is still not explained and if it is confirmed will be an important sign of some non-equilibrium process in the Martian atmosphere.

NASA's Mars Observer arrived at the Red Planet in September 1993 but unfortunately contact with the spacecraft was lost.

The Mars-94 and Mars-96 missions are being prepared in Russia for launch in 1994 and 1996 respectively. The difficult economic situation in Russia is causing problems, but, realizing the importance of maintaining the existing potential for space studies as well as the importance of fulfilling international obligations in collaborative programmes, the Russian government is supporting the projects. Scientific organizations in 20 countries are also participating in the two programmes.

Unfortunately, the Mars Network (MARSNET) was not selected as the next ESA M2 mission, but this was due mainly to programmatic reasons. A revised version is expected to be studied in tandem with NASA's Mars Environmental Survey (MESUR) programme and other international initiatives to continue the scientific exploration of Mars into the next century.

D. Trace Species In The Earth's Atmosphere

A number of space missions have studied the trace gases in the middle atmosphere and lower thermosphere. The UARS satellite has provided important information on ozone distributions. Also the Imaging Spectrometer Observatory (ISO) on the Atlas-1 mission measured the OH concentration. The Exceede-3 rocket experiment measured ozone emission produced by electron beam interaction with the atmosphere.

COSPAR's Task Group on the International Reference Ionosphere (IRI) is charged with the development and improvement of an international standard model for the most important ionospheric parameters. The latest version, IRI-1990, describes the global and temporal variations of electron and ion densities and temperatures through the whole ionosphere for magnetically quiet conditions. During the current improvement cycle IRI investigations are focused on the development of better representations of the topside electron density profile and on better mapping procedures for the highly structured regions around the magnetic equator and the magnetic poles. Major improvements of the ion composition model will be implemented in the next edition of IRI, based on studies using large amounts of ion mass spectrometer measurements from the AE-E, OGO-6, ISIS-2, TAIYO, INTERCOSMOS-1300, AE-C and AE-D satellites and from more than 100 rocket flights.

The IRI group is giving highest priority to the improvement of the topside density, because of its importance for a wide range of applications including satellite navigation and satellite altimetry. The topside modelling effort is relying on data collected by topside sounders flown on the Alouette and ISIS satellites through the sixties and seventies. Only a small percentage of these data was used for establishing the Bent-1972 model, which is still the most widely applied topside model.

Worldwide maps of ionospheric characteristics are well established and fairly reliable in middle latitudes, but much needs to be done in the magnetic equatorial and polar regions. Electric fields of magnetospheric and ionospheric origin significantly affect the distribution of ionization in these regions. The IRI group decided that regional modelling needs to be considered for these regions and several methods have been proposed for this purpose.

An IRI meeting on "Verification and New Development of IRI" was held on September 3rd 1992 during the COSPAR/IAF World Space Congress in Washington, D.C., resulting in several model improvements which will take effect with the 1994 edition of IRI. A week-long IRI Workshop was organized for late October 1993. The meeting was held in Trieste, Italy at the International Centre for Theoretical Physics (ICTP) of UNESCO and the International Atomic Energy Agency. Entitled "Off-Median Phenomena and IRI", the workshop focused on ionospheric variability and irregularities. For 1994 the IRI group is coordinating a two-day session on "The High-Latitudes in IRI" as part of the COSPAR General Assembly in Hamburg, Germany.

During 1992 and 1993 major contributions to the IRI effort were received from groups in India, China, Brazil, UK, Japan, USA and Russia underlining the international character of the IRI project. New Working Group members were accepted from Brazil, Argentina, Japan, France and Australia.

E. Active Experiments

Active experiments in space plasmas are comprised of plasma and neutral injections, energetic beams, wave injections and vehicle environment interactions. Advances have been made in experimental, theoretical and computational studies from all of these areas during the past year.

Between May and July of 1992, eight rockets were launched from the north coast of Puerto Rico to conduct a variety of active experiments during the last phase of the Combined Release and Radiation Effects Satellite (CRRES) programme. The diverse experiments involved barium ion clouds and electron attachment releases with and without the powerful HF transmitter located near Arecibo Puerto Rico. For the first time, *in situ* measurements were made by instruments flying though the modified regions over Arecibo. The incoherent scatter radar at Arecibo supported all of these experiments. The analysis of these events, together with CRRES below, forms a central part of international active experiment activities.

Analysis of chemical releases from the CRRES satellite is progressing. Plasma processes such as critical ionization velocity (CIV), diamagnetic cavity formation, and plasma structuring is now better understood as a result of the CRRES experiments. Tracing of the plasma cloud motions is being studied by scientists from the United States, Europea, and Russia scientists to determine the natural circulation of the upper atmosphere plasma.

The plasma turbulence in the boundary layer of artificial negative ion clouds has been measured during the NASA-sponsored NICARE-1, NICARE-2 and CRRES/AA-4 experiments. The boundary layer structures are narrow cavities and spikes that are a few metres in diametre. Recent computer simulations using two-dimensional hybrid codes have duplicated the measured turbulence.

Besides the Arecibo/CRRES experiments, many new achievements have occurred using ionospheric heaters around the world. Stimulated electromagnetic emissions (SEE) from Tromso, Norway, and Sura, Russia, have been produced using controlled transmission of high power radio waves. The relationship of SEE to electron cyclotron harmonics and to artificial plasma irregularities has been established. Oblique heating using the Voice of America (VOA) produced sidebands from non-linear interactions in the ionosphere.

Experiments have been conducted using electron and ion beam injections from satellites and the United Space Space Shuttle. The Space Shuttle provided the platform for Space Experiments with Particle Accelerators (SEPAC) during the Atmospheric Laboratory for Applications and Science (ATLAS-1) mission in March and April, 1992. Interactions between the 6.25 keV electrons from SEPAC and the ionosphere generated plasma waves. During the Russian Active Plasma Experiment (APEX) Programme, the Magion-3 sub-satellite recorded spectral broadening of ground based VLF transmissions using electron beam injections from the Interkosmos-25 (APEX) satellite. Particle beam antennas were used during the Change-2b electron accelerator experiment. Modulated electron beams seem to be good radiators in space but no signal has ever been received on the ground from one.

The United States Tethered Sub-satellite (TSS-1) mission was a disappointment in that the deployment mechanism was only able to release 50 ft of the tether. The electric potential set up was less than would have been achieved with a full extension. Analysis of the results from TSS-1 is progressing and a reflight of the mission is being planned. Nevertheless, significant data on tether properties was collected from a secondary payload deployed from a Delta GPS launch. The experiment, called SEDS-PMG, tested the current-conduction properties of probes in the ionosphere using biased hollow cathodes at each end of a 500 metre tether.

IV. SPACE PLASMAS IN THE SOLAR SYSTEM

The most tenuous regions of the solar system are in the plasma state, the upper levels of the Earth's atmosphere, the outer corona of the Sun, the solar wind, the ionized atmosphere of each of the planets, the magnetospheres of Jupiter and Saturn and the extended plasma

environments of comets. The bulk of our firm knowledge of the physics of plasmas in space comes from measurements made *in-situ* by space probes but additional information has come from balloons, rocket probes, and ground-based facilities, such as radars.

An important new era was opened this year by the Ulysses mission. After passing Jupiter, Ulysses is now entering the fully exploratory phase of its mission as it keeps climbing out the ecliptic plane. At the present it is at 40°S heliographic latitude. At this latitude, Ulysses measurements no longer show the slowest components of the solar wind. Such winds are typical of the equatorial neutral sheet regions, indicating that the spacecraft has entered the Sun's polar region which has never been done before. In mid-1994 Ulysses will be over the south pole of the Sun and in mid-1995 over the north pole.

Important new data on the Earth's auroral regions, with very high time resolution, have been provided since October 1992 by the Swedish/German Freja satellite, following on from the extremely successful Swedish Viking mission. Flying at altitudes less than 1750 km, Freja is investigating the lower reaches of the auroral acceleration region where the interaction with the ionosphere manifests itself most clearly. In 1994, launch of the FAST satellite within NASA's small explorer programme will study the higher altitude region with even higher resolution.

Four NASA spacecraft launched in the 1970's have now travelled to great distances in the heliosphere. Pioneers 10 and 11 are on opposite sides of the Sun, the former having passed the 50 AU mark. Voyagers 1 and 2 are also in the 40 to 50 AU region. Plans have been made for recognizing passage through the heliopause, if and when it is encountered. The heliopause marks the limit of the Sun's direct influence in space, and the possibility of reaching this frontier is eagerly awaited. First warnings of the approaching heliopause have been received this year in the form of electromagnetic waves in the few-kHz regime.

The Galileo Jupiter orbiter making its way slowly through the solar system to its rendezvous with the planet later in the decade has also been able to monitor the heliosphere this year. The second Galileo Earth encounter in December 1992 provided another interesting pass through the Earth's magnetotail. After the failure to deploy the large antenna, a new mission plan is in effect which relies on the low-gain antenna. However through the introduction of new schemes for onboard data compression as well as ground signal-to-noise improvements, the effective data rate has been increased by a factor of 100.

A major set-back was the loss of the Mars Observer mission this year. Although not primarily a mission directed at the ionized atmosphere of Mars, it would no doubt have returned new information on the state of the upper atmosphere and the magnetism of that region and the planet itself.

The Japanese Akebono spacecraft is continuing to provide new data concerning low-altitude plasma in the Earth's magnetosphere. Also in the Earth-system, the Sakigake probe, primarily a cometary mission, made passes 3,000 Earth-radii downstream of the Earth, the first

in September 1992, another in July 1993. Analysis of the first pass indicates the presence of the Earth's magnetotail even at these large distances.

During the 1990s, space agencies in Japan, the United States, and Western Europe and Interkosmos/IKI in Eastern Europe have been implementing a large multi-spacecraft programme, referred to as the Inter-Agency Solar-Terrestrial Program (IASTP), to investigate plasma processes in the near Earth space in the next decade. The Japanese contribution to this program is the Geotail spacecraft, launched in July 1992. Geotail is exploring the magnetotail of the Earth's magnetosphere but because of its unique orbit is also contributing valuable dayside magnetopause data. First results indicate that the magnetotail even at distances as large as 220 Earth-radii is often characterized by "closed" magnetic field lines connected to the Earth. In September, Geotail underwent a special lunar eclipse manoeuvre which successfully undid a latch-up condition in one of the instruments.

The NASA contributions to the IASTP, namely the Wind and Polar missions, are scheduled for launch in April and June 1994, respectively. Wind will study phenomena in the solar wind and monitor conditions upstream of the magnetospheric system while Polar will study the distant polar magnetosphere.

Eastern European scientists are contributing a program called Interball. The mission will feature pairs of spacecraft in low and high orbit respectively with the aim of further studying the interrelationship of ionospheric and magnetospheric processes. The first spacecraft pair, Interball-Tail, is scheduled for launch in march 1994, the second pair, Interball-Aurora, in June 1994.

This phase will be followed by the ESA-led Cluster mission, wherein four spacecraft will fly in close formation to study field and plasma microstructure in the magnetosphere and its boundaries and provide insight into processes relevant to solar and astrophysical contexts. In particular, fundamental physics will result from the first use of multi-point measurements in the high latitude magnetosphere. The Solar and Heliospheric Observatory, SOHO, another ESA cornerstone mission, with its mix of remote sensing and *in-situ* measurements will investigate solar and interplanetary processes, many of which are closely related to those pursued by Cluster and the other IASTP missions.

Active experimentation in space has received increased interest in recent years. Following on from the CRRES mission, which ceased operation in 1992, the Russian APEX spacecraft launched in December 1991 is currently performing such active experiments.

As is apparent from the numerous existing and planned missions, this area of research is active with exciting programmes. As is regularly noted in these reports, it is important to remember that, although the core research in space plasma science must be through *in-situ* measurements from space platforms, there are international ancillary programmes of ground-based observations of various kinds, with telescopes, radars, magnetometer chains, rheometers, etc. Often significant contributions can be made fairly cheaply by scientists working

in less developed countries. Furthermore, unique measurements are made by means of balloon-borne instrumentation and instruments carried on sub-orbital rocket flights.

V. RESEARCH IN ASTROPHYSICS FROM SPACE

A. Galactic and Extragalactic Astronomy

Through access to space, astronomy and astrophysics can address problems throughout the entire electromagnetic spectrum and many substantial discoveries have resulted, particularly at those wavelengths which are not able to penetrate the Earth's atmosphere. With the successful launch of the NASA Extreme Ultraviolet Explorer (EUVE) mission, the continued success of the Germany/United Kingdom/United States. Rosat observatory and the use of the NASA Compton mission for observations at gamma-ray energies, virtually the entire electromagnetic spectrum has now been covered to a roughly equivalent level. Future astronomical spacecraft will increasingly tend to expand on this knowledge base through detailed studies of spectra and time variability, and by specialist observations designed to clarify the structure of the Universe from the earliest epoch and the nature of the possible non-baryonic or "dark" matter whose existence is required by observations of the dynamic behavior of galaxies both in isolation and in clusters.

In the face of increasingly serious budgetary pressures on many national space agencies, the rate of launching of astronomical spacecraft has been somewhat reduced. During the past year, only the Japan-United States Asca (Astro-D) mission and the United States-Germany Orfeus UV telescope have also been launched, the latter on an eleven day Shuttle mission which successfully deployed the German Astrospas free flying platform which was later retrieved and returned to Earth.

In the following sections which are organized by wavelength range, the results achieved by the various national and international space agencies during the past year will be outlined along with the status of future missions.

1. Infrared, Submillimetre and Radio Spectral Ranges

Following the publication by NASA's COBE investigators of the detection of a microwave background anisotropy, further analysis of the data has confirmed and strengthened the original conclusions reached last year. Confirmation by ground-based techniques has also been achieved and understanding of the early Universe and its origin has been placed on a firmer footing.

In spite of the strong support given by the Bahcall Committee to the NASA Space Infrared Telescope Facility (SIRTF), a cooled 0.9 m telescope for imaging and moderate resolution spectroscopy in the 2-700 μm range, a new start for this programme continues to be delayed. However in view of the importance of the infrared spectral range, a further NASA

Small Explorer mission in this area has been selected to complement the infrared/sub-mm astronomy mission that is already in the NASA programme with a planned launch in 1996.

Funding pressures in both Germany and the United States have continued to delay the Stratospheric Observatory for Infrared Astronomy (SOFIA) project which involves the construction of a 2.7 m, sub-mm and far infrared telescope for flight on a NASA aircraft. This telescope would be designed for repeated flights above most of the Earth's water vapour to provide very high spectral resolution for wavelengths in the 30-350 μm range together with diffraction limited imaging at the 2.5 arcsecond level. It is hoped that it will eventually be possible to carry out this significant programme.

The ESA Horizon 2000 science programme includes the Infrared Space Observatory (ISO) mission which contains a cooled 0.6 m telescope instrumented to observe in the wavelength range 2-200 μm with a total of four instruments capable of imaging, photometric, polarimetric and high resolution spectroscopic observations. The original launch date has been delayed but development problems with cryogenic valves have now been solved and the currently scheduled launch date of September 1995 looks increasingly likely to be achieved. Following commissioning, ISO will be used as an observatory with approximately 35 per cent of its observing time during its planned 18 month lifetime available to the ESA community at large. In addition negotiations have been successfully completed with Japan and the United States for the provision of an additional ground station which will now further increase the observing efficiency of the mission by permitting a significant increase in the available observing time.

A major mission or "cornerstone" of the ESA Horizon 2000 programme is the Far Infrared Sub-mm Telescope (FIRST). Designed to explore the 50-1000 μm spectral range, the mission will comprise a passively cooled telescope with a 3 m aperture. Cost studies have now indicated that both high resolution heterodyne spectrometers and cooled Fabry-Perot interferometers can be accommodated. Work is continuing to further define the mission. During the ESA selection process in November 1993, the Agency chose FIRST as the fourth cornerstone of Horizon 2000. This selection will allow the FIRST mission to benefit from a range of long-term technological developments in the design of mechanical and other cryogenic systems.

2. Optical and Ultraviolet Spectral Ranges

The International Ultraviolet Explorer (IUE) mission, which was launched in January 1978, is now in its 15th year of operation. The programme involves NASA, ESA, and the United Kingdom's SERC. Low and high dispersion spectral observations are undertaken in the wavelength range 1150 to 3200Å and the spacecraft's geosynchronous orbit ensures a high observing efficiency coupled with a unique ability to study variable phenomena. The maintenance of comprehensive data archives by the collaborating nations has greatly enhanced the value of the mission for astronomers worldwide. Operations are set to continue into 1994 but budgetary pressures could threaten continued operation of the mission in later years. In recent observations of Seyfert and other Active Galactic Nuclei, study of the time lags between

emission line and continuum variability is providing new information on the size and detailed geometry of the emitting regions.

The NASA Far Ultraviolet Explorer (FUSE) mission, which is designed to observe at high spectral resolution in the important 150 to 1200Å range, is likely to become a worthy successor to IUE. This spacecraft, which should be launched in 2001, will offer a significant improvement in sensitivity in the cosmologically important 900 to 1200Å range over the Copernicus satellite which carried out the only previous observations in this wavelength interval. The mission is now in Phase B and undergoing detailed design and cost analyses which may result in changes to the design of the UV telescope and to the wavelength range to be covered.

The Germany-United Kingdom-United States Rosat mission has completed the first full survey of the extreme ultraviolet sky in the wavelength range 60 - 400Å. The survey was undertaken by the United Kingdom's Wide Field Camera instrument. Following the publication of a catalogue of the positions of 400 bright sources, work is well advanced on preparing a complete catalogue of approaching 1,000 sources which will be published in the near future. The mission is now well into its observatory or pointed observation phase with time being awarded on a competitive basis.

Following NASA's launch of the Extreme Ultra-Violet Explorer (EUVE), a further all-sky survey is being undertaken in this spectral range together with some follow-up spectroscopic studies using a grazing incidence spectrometer. The instruments are operating exceptionally well and first results from the mission are extremely encouraging. Time is being awarded to the community for use of the spectrometer as part of a Guest Investigator programme and the mission continues to be highly successful.

Orfeus is a 1 m class ultraviolet telescope which operates in the 500 to 1200Å wavelength range. A joint project of NASA and Germany, the telescope, mounted on the German Astrospas platform, was deployed from the Shuttle cargo bay and successfully carried out a range of observations. Instrumentation included three ultraviolet spectrometers provided by groups form the University of Tübingen, Germany, the University of California at Berkeley and Princeton University, United States.

The ESA Hipparcos spacecraft launched in August, 1989, failed to achieve its planned geostationary orbit and instead remained in an elliptical transfer orbit. However, thanks to the outstanding efforts of the ESA project team the satellite has nevertheless been operating extremely successfully. It has now exceeded its original aims and has measured the parallaxes and proper motions of some 120,000 stars with a precision of 1-2 milli-arcseconds. Following a progressive series of radiation-related problems due to being placed in the wrong orbit, the mission operations were terminated in August, 1993. However in addition to the exceptional astrometric results, high quality photometric measurements have been completed for each star. Final data processing will be complete in 1996 after which time the data will be available to the international scientific community.

NASA's Hubble Space Telescope (HST), launched in 1990, was the first of the Great Observatory satellites. In spite of the well known difficulties related to the figure error in the telescope's primary mirror, results of the highest quality continue to be obtained. In particular, use of the Faint Object Camera has allowed the identification of the source of X-ray bursts in the globular cluster NGC 6642. The burst emitter is now believed to be a binary system comprising a white dwarf and a neutron star. The principal refurbishment activity successfully completed by a Space Shuttle crew in December 1993 involved the provision and fitting of a system of corrective optics which will hopeful restore the telescope's angular resolution to the levels originally planned. In addition new solar arrays were fitted in order to eliminate a small but significant pointing jitter induced by a thermal system design problem on the initial configuration. A new version of the Wide Field Planetary Camera was also installed.

3. X-rays and Gamma-Rays

The NASA Gamma-Ray Observatory which was launched in April, 1991, continues to operate very successfully although hampered by the failure of its tape recorders. However more than 50 per cent of the data are being collected by the NASA Tracking and Data Relay Satellite (TDRS) system. The spacecraft includes four instruments: (i) the Burst and Transient Source Experiment (BATSE), which operates in the range 0.03-1.9 MeV to locate burst and transient sources with a precision of 1 degree in a large field of view; (ii) the Oriented Scintillation Spectrometer Experiment (OSSE), which conducts gamma-ray line observation and positions sources with 10 arcminute accuracy in the range 0.1-10 MeV; (iii) the Imaging Compton Telescope (COMPTEL), which positions sources to an accuracy of 8 arcminute within a large field of view in the 1-30 MeV range; and (iv) the Energetic Gamma-Ray Experiment Telescope (EGRET), which is spark chamber operating in the 20 MeV to 30 GeV range. It is clear that with the simultaneous and complimentary operation of the Russian GRANAT mission, the field of gamma-ray astronomy will witness major advances over the next several years.

Although the Japanese Ginga spacecraft, launched by the Institute of Space and Astronautical Science (ISAS), re-entered the Earth's atmosphere, data from this very successful X-ray astronomy mission continue to be analyzed with particular emphasis on the nature of quasars and other active galactic nuclei. Work at ISAS has now culminated in the launch of the Astro-D mission, renamed Asca, in February 1993. This mission, which includes instruments provided by groups in Japan and the United States, uses broad-band flux collectors of high sensitivity for observations in the 0.5-10 keV energy range. It is performing flawlessly and its CCD detectors with resolving power of more than 50 at 7 keV, are providing spectra of a wide range of important and interesting objects. In addition, studies are in progress in Japan for a spacecraft which could carry a large imaging X-ray telescope into orbit after 1996.

Preparations for the Russian Spectrum X mission are well advanced for launch in 1995. The spacecraft will be placed in a highly elliptical orbit for enhanced observing efficiency. It includes a wide range of X-ray instruments supplied by groups in the C.I.S., Finland, Germany, Italy, Switzerland, the United Kingdom and the United States.

The Germany-United Kingdom-United States Rosat mission has now completed its all-sky survey in the energy range 0.1-2.5 keV and has catalogued almost 100,000 sources. The mission is now in its fourth year of operation and is continuing to act as a highly successful X-ray observatory which is heavily oversubscribed in the use of observing time.

The X-ray Timing Explorer (XTE), which will comprise the largest area proportional counter array yet flown, is now likely to be launched on a dedicated spacecraft in 1996. With an array of scintillation detectors in addition to the X-ray proportional counters, the mission will concentrate on high temporal observations of variable sources in the energy range 0.5-200 keV. An all-sky monitor which can survey 80 per cent of the sky in 30 minutes is also included.

The Advanced X-ray Astrophysics Facility (AXAF), part of NASA's Great Observatory series of missions, has been reconstructed following budgetary difficulties. Two missions are envisaged: one to be launched in 1998, which will employ a high resolution X-ray telescope (< 1 arcsecond) and will concentrate on imaging and source positioning observations and a second, which may be launched 18 months later, which will emphasize large collecting areas and spectroscopic performance at the expense of angular resolution.

The X-ray Multi-Mirror (XMM) mission is the second cornerstone of the ESA Horizon 2000 programme. It is comprised of three nested grazing incidence telescopes and offers nearly 20 times more collecting area than AXAF at 7 keV, with an angular resolution of better than 20 arc second. The mission will therefore concentrate on high throughput X-ray spectroscopy and will complement the AXAF observatory. It is equipped with CCDs, refraction grating spectrometers and a separate 0.3 m optical telescope which will permit simultaneous observations in the wavelength range 1500 to 10,000Å.

In the field of space astronomy, the Integral Gamma-ray Astronomy mission has been selected for the next ESA medium-scale mission of the Horizon 2000 programme. The model payload includes an imaging system operating in the 70 kev to 10 MeV energy range, a high resolution Germanium spectrometer to study X- and gamma-ray line emission in the range of 15 keV to 10 MeV with a resolving power of ~ 500 at 1 MeV, an Optical Transient Camera to search for the visible light counterparts of gamma-ray bursts and an X-ray Monitor which will obtain spectra in the 3-100 KeV range using a high pressure proportional counter.

Work is continuing on the Italian SAX X-ray astronomy mission, which includes groups from the Netherlands and from the ESA-ESTEC Centre. The spacecraft, which will operate in the 0.1-200 keV energy range, should be launched in 1995. It is distinguished by its broad energy coverage, its combination of pointed and survey instruments and the very low detector background which will be achieved by virtue of its near-equatorial orbit.

B. Solar Physics

1. Solar Activity

In the past three decades the greatest advances in solar physics from space have occurred in the domain of high-energy emissions such as ultraviolet, extreme-ultraviolet and X and gamma-ray photons, charged particles and neutrons. In particular, the Solar Maximum Mission (SMM), in orbit from 1980 to 1989, through its coordinated studies over a wide range of radiations, has made very significant contributions to the understanding of flare phenomena. This emphasis on coordination will be a key element in many future projects. The space environment (free of atmospheric effects harmful to observation) has also greatly advanced certain visible light studies by coronagraphs and high-resolution imagers, which have contributed to our understanding of the role of solar magnetic fields and of transient phenomena in the interplanetary medium. The combined observation of high energy emissions and magnetic field dynamics represents a key strategy for understanding the mechanism of solar flares and other transients. The launch of the satellite Yohkoh is already leading towards further important advances in our understanding.

2. The Quiet Solar Atmosphere

Since the "quiescent" solar chromosphere and corona have such high temperatures, they are best observed at shorter wavelengths, in the ultraviolet and extreme-ultraviolet. The main problem here is to understand the mechanism whereby a small fraction of the mechanical energy resident in the convective motion of the lower, cooler photosphere is transferred upwards to result in the heating of the corona and the acceleration of the solar wind. According to the laws of thermodynamics, this transport must be effected by non-thermal means since heat cannot be transported in the direction of a positive temperature gradient. Results from spaceborne instruments, such as those flown on Spacelab, rocket flights and other missions, with the invaluable cooperation from ground-based observations, have clarified a number of issues. We now have a picture of the three-dimensional structure of temperature and density, as well as the importance of continuous fine scale dynamic effects in the solar plasma and in the related magnetic field structures. The scale of the participating structures ranges from the limit of present-day telescopes (a few hundred kilometres on the solar surface) to large-scale unipolar regions called coronal holes. The observations clearly demonstrate the critical role of small-scale magnetic field structures in the transport process. Some of the previously proposed transport mechanisms can now be excluded, and there are some very positive pointers to the correct interpretation. Theoretical models based on either wave transport or stochastic processes may be equivalent in the final analysis, since any wave interpretation must involve extreme nonlinear amplitudes.

3. The Solar Interior

The techniques of space research are now being brought to bear on the understanding of the structure and dynamics of the solar interior and convection zone, in exploiting the new field

of helioseismology. This field, developed over the past 20 years using observations from the ground, studies the modes of vibration of the global Sun, and interprets them in terms of the internal physical properties. Making observations in space removes the two obvious limitations of the day/night eclipsing and the atmospheric degradation. In particular, vehicles which orbit far from the Earth offer the possibility of long periods of uninterrupted solar viewing. The first space observations in a near-Earth orbit were obtained from the SMM satellite. More recently, while on the way to Mars, the Soviet Phobos spacecraft provided continuous data over a period of many months. Preliminary analysis of the Iphir experiment on Phobos shows very fine detail on the 5-minute global p-mode spectrum, which throws important light on the excitation mechanism for the modes. Three ambitious experiments are planned for the SOHO mission. These observations will help resolve the questions posed by the enigmatic low solar neutrino flux, as well as the internal differential rotation, convection and the generation of the solar magnetic fields. Other studies are planned, eg the SOYA instrument to be flown on the Russian Mars-94 mission in 1994 and other photometers planned for the Russian Coronas missions in 1994 and 1995. Extension of these techniques are planned also for other stars, with the EVRIS instrument on Mars-94 and the PRISMA (Probing Rotation and Interior of Stars) project under study by ESA.

4. The Solar Interplanetary Connection

Studies of the corona from space have shown the importance of the so-called "coronal holes", large areas of the solar surface with well defined boundaries, in which the corona has a much lower density. It is now accepted that these areas are those with an open field structure connected directly to interplanetary space. They are the major source of the steady solar wind and their understanding is thus crucial for the problem of solar (and stellar) mass loss and, ultimately, for stellar evolution. Their relation to the solar wind has so far been studied only in the ecliptic plane. With Ulysses, which is now heading southward out of the ecliptic plane, it will soon be possible to examine the role of the polar coronal holes, which it is thought could show a significantly larger wind flux.

5. Recent and Future Missions and Programmes

There are now two major thrusts in the new missions currently planned. The first covers the study of activity during the present and next solar cycles, with missions such as Yohkoh, balloon projects and a future Japanese flare mission. The second relates to the quiet solar corona and its interaction with the interplanetary medium, with the missions Ulysses, Wind, Coronas and SOHO. In addition, opportunities will be exploited to pursue the techniques of helioseismology (SOHO), as well as to take advantage of the solar observing capabilities of certain astronomical missions (Sigma and GRO).

6. Yohkoh

The Yohkoh mission, launched by Japan in August 1991, carries a complement of instruments to monitor energetic flare phenomena and the evolution of coronal magnetic

structures. This is the only satellite totally devoted to solar observations during the current maximum. Its payload includes a high resolution soft X-ray telescope (SXT) provided by the United States and a Bragg crystal spectrometer developed jointly by experimenters in the United Kingdom and the United States. The Japanese instruments include an advanced Fourier-synthesis hard X-ray telescope providing a much improved sensitivity, energy range, and spectral resolution than imaging detectors previously flown aboard the SMM and Hinotori missions. Higher energy X-rays, gamma rays and neutrons are also being monitored by Yohkoh instruments.

Significant improvements in temporal resolution e.g. 2 seconds in gamma ray spectra as compared to the 16 seconds of the SMM spectrometer, should provide new insights into the understanding of the particle acceleration and interaction processes in flares. All instruments have been functioning well. After an intense investment in the complex operations control, a detailed analysis is now beginning. The SXT instrument with its dramatic images, has rapidly shed light on the evolution of the corona. Movies assembled from its synoptic data, show a "quiet" corona in constant change, on a wide range of time-scales. Preliminary analysis suggests a continuous outflow of coronal material from the active region sites.

7. Ulysses

Ulysses, formally known as the International Solar Polar Mission, was launched in October 1990 on its long journey to study the solar poles from outside of the ecliptic plane. During its recent passage by Jupiter, it has used the planet's gravitational field to deflect its trajectory so as to pass over both solar poles at a distance of around 1 AU. Ulysses carries a variety of particle detectors for studying the solar wind *in situ*, as well as two small scintillation detectors for observing X-rays from 15 to 150 keV. Ulysses has already sent back a wealth of valuable information on the interplanetary medium near the ecliptic plane, including its interaction with the penetrating effect of the interstellar medium. It is now leaving the ecliptic on route towards the polar regions. It is thought that much of the solar wind seen in the ecliptic plane at 1 AU arises from the solar polar regions. It is therefore highly probable that the wind that we know at present is not typical of the general solar wind, which might be quite different perpendicular to the ecliptic plane. In October 1993, Ulysses at 40°S off the ecliptic plane is already observing new characteristics in the structure of the solar wind. Ulysses thus offers the promise of advancing significantly the understanding of solar evolution and mass loss, with evident interest for other stars as well.

8. Sigma

Sigma is a French experiment aboard the Russian Federation's GRANAT satellite. Although its main objective is to map the gamma-ray sky and locate non-solar sources, its cosmic gamma-ray burst detectors are also obtaining flare spectra up to energies of 100 MeV. Sigma is also designed to make high sensitivity and temporal resolution observations of flare emission in the 50 keV to 7.5 MeV range, and is accumulating a body of important solar data.

9. Wind

The Wind spacecraft, a component of the Global Geospace System (GGS), which is part of the International Solar-Terrestrial Program (ISTP), carries a high-purity germanium detector of solar flares and cosmic gamma-ray bursts in the 25 keV to 8 MeV energy range. In addition to gathering information on gamma-ray lines due to accelerated particles in large events, the spectrometer provides nearly continuous monitoring of hard X-ray emission from flares, with spectral resolution superior to that of the SMM spacecraft.

10. Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO) is NASA's major mission in high-energy astrophysics. GRO was launched early in 1991 and carries four large instruments with the objective of obtaining comprehensive observations of cosmic sources in the 20 keV to 30 GeV energy range. GRO is also well-suited for observing solar radiation, gamma-ray and accelerated neutrons, which are evidence of the most energetic processes occurring in flares. Of the four instruments, the Burst and Transient Source Experiment (BASE) has the greatest capability for flare observations, due to its large sensitive area. It should provide extensive high temporal resolution observations of flare emission in the 50 to 1000 keV energy range. Observations of the nuclear line region of the spectrum are being provided by two other instruments, the Oriented Scintillation Spectrometer Experiment (OSSE) and the Imaging Compton Telescope (COMPTEL), while the Energetic Gamma-ray Experiment and the Telescope (EGRET), which covers the 20 MeV to 30 GeV portion of the spectrum, probes the most energetic phenomena on the Sun.

11. Coronas

Coronas is a series of Russian satellites which were scheduled for launch at the end of 1993 and which were designed to observe the solar atmosphere from near-Earth orbit, and to observe solar activity, and magnetospheric solar effects. They will carry a number of instruments developed by groups from the former Soviet Union, in collaboration with groups in many other countries. Current plans include X-ray spectrometers, multi-layer imaging telescopes and coronagraphs, as well as studies in helioseismology.

12. Balloon Programmes

Several countries, including China and the United States have plans to carry out balloon observations with instruments dedicated to flare physics. Many of these will be carried out in long-duration balloon flights. In the case of the United States, the Max 91 program includes the flight of the High Resolution Gamma-Ray and Hard X-ray Spectrometer (HIREGS), which will be able to investigate the region 15 keV to 20 MeV with high spectral resolution.

13. The International Flares 22 Project

In an international effort similar to the successful Solar Maximum Year (SMY) program of the early 1980's, the international solar community is joining forces once again in a programme of flare research at the maximum of cycle 22. Flares 22 is an integral part of the Solar Terrestrial Energy Program (STEP), sponsored by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP). Research on active phenomena will require the analysis of data from many individual spacecraft and balloon experiments, as well as from highly improved ground-based observatories. Flares 22 focuses international attention and collaboration on the analyses of these data and on subsequent theoretical work.

14. SOHO

ESA, in collaboration with NASA, is developing the Solar and Heliospheric Observatory (SOHO), which is scheduled for launch in 1995. It will orbit the L1 Lagrangian point at over a million kilometres from Earth, a location that offers continuous viewing of the Sun and is an ideal site for *in situ* wind measurements and helioseismology. SOHO is the most ambitious solar project developed so far. Its instruments will probe the entire Sun, from its center by means of helioseismology, its outer atmosphere by remote sensing visible and ultraviolet observations, and the wind at 1 AU by *in situ* studies. Instruments are being provided by consortia in Europe and the United States. The helioseismology instruments include Global Oscillations at Low Frequencies (GOLF), Variability of Solar Irradiance (VIRGO) and Michelson Doppler Imager (MDI:SOI). These will measure global oscillations, the solar radiative output and surface magnetic fields. A detailed study of the solar atmosphere from the chromosphere to the corona is the subject of study for the Coronal Diagnostic Spectrometer (CDS), the Solar Ultraviolet Emitted Radiation (SUMER) instrument and the EUV Imaging Telescope (EIT). The higher corona will be observed by the Ultraviolet Coronograph Spectrometer (UVCS) and the LASCO white light and spectrometric coronograph. Combined, these instruments can measure the temperature, density, composition and velocity of solar plasma at various heights, with the aim of deriving the balance of energy and mass up to a height of 30 solar radii. Solar Wind Anisotropies (SWAN), Charge Element and Isotope Analysis (CELIAS), Comprehensive Suprathermal and Energetic Particle Analyzer (COSTEP) and Energetic and Relativistic Nuclei and Electron Experiment (ERNE) instruments will provide information on the solar wind. These instruments will study the wind structures and relate them to coronal structures and dynamics.

15. Projects for Future Missions

A number of projects are under study in view of the obvious need to ensure further progress of solar physics in the next century. The Orbiting Solar Laboratory (OSL), with a minimum lifetime of three years, would have been an observatory-type mission in a polar orbit, which would have provided continuous images and spectra in white light, ultraviolet and extreme ultraviolet, with 0.1 arc sec resolution. The programme has been delayed substantially by recent planning decisions, and its ultimate configuration will be re-examined before further consideration is given. Japan is preparing plans for its next solar mission, to follow Yohkoh, some ten years

after that programme ends. Plans to extend the measurement of global oscillations in intensity to solar-type stars are also under consideration. A preliminary experiment is planned for the Russian Mars-94 mission, while a more ambitious programme is the subject of an ESA mission definition study called "STARS". These ideas, among others, could serve to ensure a bright future for solar physics at the start of the next millennium. Solar observations benefit enormously from opportunities to develop new instrumental techniques, provided by simple short missions. In this regard, the rocket programme of the United States has been of great value, and it is hoped that it will continue. ESA's EURECA programme and NASA's Spartan programme, both of which utilize the Space Shuttle, will also prove important in this field.

VI. LIFE SCIENCES AND SPACE RESEARCH

A. Gravitational Biology

1. Space Medicine

During the last two years, several manned space missions of short and long duration were performed on the Russian orbital station Mir as well as on the Space Shuttle. On Mir, a constant human stay in space was ensured. The maximum length of each Mir crew mission was six months. As in the past, much work was carried out by cosmonauts and astronauts during EVAs. During their missions the cosmonauts and astronauts enjoyed good health and maintained high operational performance due to a set of medical preventive measures and adequate sanitary/hygienic conditions aboard the transport vehicles and in orbit.

Investigations into how microgravity effects the human body were predominantly concerned with the shifts in the sensorimotor function and the skeleton. The velocity and force indices as well as the endurance of muscles was shown to decrease starting, in a literal sense, from the first days in microgravity. These changes are more noticeable in the legs than in the arms and exhibit similar patterns in the leg flexors and extensors. The peak of these changes was noticed by the end of the first month in flight. A drastic decline of the motor control precision was also discovered and this condition persisted throughout the six-month flight. These developments are attributed to the functional shifts in the sensory systems hindering motion programming, and the reduction of the muscular tone which makes motor control in the multicomponent system more difficult.

The microgravity-induced changes in the mineral composition of the human skeleton were proved to be systemic, i.e., bone losses were most significant in the pelvis and the limbic vertebrae, whereas the upper part of the skeleton (skull, thoracic vertebrae, arms) displayed a consistent increase of their mineral densities.

These losses depend on the biomechanical function of a particular part of the skeleton on Earth and the amount of in-flight exercising rather than on the length of a mission. The severity

and recovery rate of bone losses vary in different individuals implying the importance of the genetic background for bone reaction to inadequate mechanical demand.

To further investigate the physiological responses and human adjustment to long-term exposure in space, a Russian physician was scheduled to embark on a 18.7 month (560 day) mission to start in November 1993. The duration of this mission is comparable with a trip to Mars. A vast biomedical programme will also comprise experiments in such disciplines as gravitational biology and physiology.

Further to the exploration of the reaction of the human body to gravity and gravity deprived stimuli, as in the weightless conditions in space, ESA mounted an effort to support the scientific community with a specialized multiuser laboratory called Anthrorack. This research facility was flown on the German Spacelab mission D-2, onboard the United States Space Shuttle Discovery in April-May 1993. The Anthrorack allowed for simultaneous investigations of the human cardiovascular system, its central and peripheral volume regulation, and the hormonal control of these processes. All investigations are on a minimum-invasive basis, and allow for a complete systems analysis in an integrated way so that the results are conclusive despite the low number of test subjects employed. For the first time, ESA also selected an experiment to study the central venous pressure with an indwelling catheter inserted before the launch, which allowed a continuous recording of the pressure in the right atrium of the astronaut's heart to be obtained. This facilitated the study of time constants, pressure changes and subsequent volume regulation in the body of this highly dynamic process. Initial results of these tests indicate a lowering of the central venous pressure, much in contrast to the prediction and current knowledge in human physiology.

2. Space Biology

The most important events in this area were the experiments conducted on various species during the Space Shuttle's IML-1, IML-2, and SL-J missions as well as those done on the Russian Biosatellite-10 (COSMOS-2229) and Mir orbital complex.

The Russian Biosatellite-10 (COSMOS-2229) was launched on December 29, 1992. In a 12.5 day mission a number of experiments were performed in cell biology (cell cultures in vitro), developmental biology, chronobiology (various insects and amphibians) and animal physiology (monkeys). The data obtained reveal new exciting aspects of microgravity's effects on living systems.

The scientific programme of the COSMOS-2229 mission also involved extensive cooperation with ESA, NASA, CNES, the Canadian Space Agency, Germany, China and several former republics of the Soviet Union. The results of the Biocosmos mission were scheduled to be discussed in detail at an international symposium planned held in Moscow on December 15-18, 1993.

As in the previous years, primary importance was given to the investigations of the microgravity and terrestrial g-force effects on cell activities. Gravity was shown to influence the reproductive function, intercellular interaction and metabolism in cells. The direct biological effects of gravity were observed parallel with those mediated by the in-flight environment. Recent experiments confirmed that g-forces may also affect the embryogenesis of amphibians and birds. In microgravity anomalies in development and viable specimen rate are noted.

A wide spectrum of investigations in gravitational biology and physiology were also planned for the September 1993 SLS-2 Space Shuttle mission. ESA, France, the Russian Federation and the United States are also working on the Bion, Rhesus, IBIS, Biobox and Biopan projects which are designated to fly in the 1994-1996 timeframe.

A frog embryology experiment was conducted on the Spacelab mission. Adult female frogs ovulated in space and produced normal offspring and the postflight reproductive potential of space-flown adults was normal. Generational studies of space-conceived and hatched offspring continue. Several experiments in cellular biology and plant physiology were conducted in space, utilizing the Biorack and Biolabor multiuser facilities available on the Space Shuttle.

Some mid-deck biological experiments were also performed on various Space Shuttle missions. The main purpose of one experiments performed on rats was to study the adaptation of bones and muscles to microgravity and to test the efficacy of exogenously supplied growth hormone and pharmacological drugs. The results of this experiment are still pending.

Preliminary results of the Arabidopsis experiment indicate poor flower formation and ovary development in microgravity.

B. Radiation Biology

1. Space Research

The assessment of the radiation environment in LEO has continued. The introduction of a tissue equivalent proportional counter specially designed for measurements in space has increased the amount of information about the environments. These measurements, with those of the German Space Agency (DARA), National Space Development Agency (NASDA) and University of San Francisco groups using particle detectors and the bubble neutron detector of the Canadian Space Agency (CSA), are revealing more about the complexity and dynamic state of the radiation environment in LEO. Changes in the trapped protons and the position of the South Atlantic Anomaly have also been detected.

Some of the experiments carried out on IML-1 in January 1992 were reported at the World Space Congress and results of further analyses have been appearing. There have been recent radiobiological experiments that covered three areas: induction of gene mutation in C elegans with correlation of the traversal of HZE particles and mutation and repair; two sets of investigations using yeast; and the study of embryonic development in Caruasius morosus. There

will also be the results from the investigations of seed and spores exposed to radiation in the EURECA satellite for about one year.

2. Ground Research

Research on the effects of heavy charged particles suffered a severe setback in 1993 with the closing down of the Bevalac at the Lawrence Berkeley Laboratory. This facility had been the major source of heavy ions for biological studies of both a basic and applied nature. The heavy ion beams were also used to provide information for transport codes essential to the design of shields for space craft. The Bevalac served not only as a resource of the United States, but one that was used by scientists from many countries and most importantly, in the training of young scientists. While the loss of the Bevalac facility will be felt for many years, it is fortunate that the SIS high energy accelerator at GSI Darmstadt is now operating on a regular basis. Biological experiments have been conducted on the effects of ions such as oxygen, neon, argon, and nickel. Currently the programme is restricted to thin targets, such as cells in cultures but development of exposure conditions suitable for animal experiments are underway.

A number of investigators are hoping to conduct experiments on exposure to heavy ions at the facility at Dubna, Russia. It is hoped that heavy ions, in a limited range of Z, will be available in the near future for biological research at the new accelerator developed at Chiba, Japan, for radiotherapy. Looking further into the future, it is hoped that a facility to replace the Bevalac will be established at Brookhaven National Laboratory in New York, United States.

The reduction in availability of heavy charged particles is resulting in an increase in the interest in studying the effects of protons.

The potential for training and research in the field of heavy ions and other radiations of importance in space has been enhanced by the establishment of two NASA Specialized Centers of Research and Training (NSCORT) in radiation health. The NSCORT, run by Lawrence Berkeley Laboratory and Colorado State University, has now been in operation for almost two years. New courses appropriate for students planning a career in space research have been started and the first few students are also involved in research projects. The research being conducted at the institutions involves: (i) microdosimetry, track structure and calculations of initial damage; (ii) repair capacity in normal human cells and analysis of defects in repair in two different mutants; (iii) use of lymphoblasts in understanding the basis of RBE; (iv) quantitative and qualitative aspects of mutation induction in human and rodent cells; (v) role of irradiated stroma and rapid tissue remodeling; (vi) helium ion-induced cataracts in humans; (vii) modelling of double-strand break-induced translocations; and (viii) risk assessment using existing biological data and related cross sections.

This year a second centre has been established with funding from DARA. This centre is a cooperative venture between the Universities of Giessen and Siegen with the German Aerospace Research Establishment (DLR) at Cologne and Gesellschaft für Schwerionenforschung

MBH (GSI) at Darmstadt. Staff representing the centres in both Germany and the United States centres have met and made plans for cooperation in future activities.

Among the various meetings that have been held at various sites during the last year dealing with space radiation was NASA's fourth annual Space Radiation Health Investigators Workshop at Dallas in March 1993. Seventeen presentations were made covering facilities and recently conducted studies. In May, the COSPAR Colloquium No. 6, International Round Table on Radiation Risk in Humans on Exploratory Missions in Space, was held at Bad Honnef, Germany. Forty-four participants from 10 countries attended this very successful meeting. After listening to presentations that summarized current knowledge of the various aspects of deep space radiation, specific groups made recommendations regarding the research required to assess the effects and risks that might be incurred from radiation exposure on deep space missions. The areas covered were: dosimetry, cellular and subcellular studies, and animal studies.

C. Planetary Biology and Origins of Life

1. Planetary Biology

As in previous years, interest in this field has continued to focus on the Mars-94 and Mars-96 missions, the joint ESA-NASA Cassini mission to Saturn and to its largest satellite, Titan, and the Search for Extraterrestrial Intelligence (SETI) programme.

Regarding Mars, topics of interest still include the problem of finding liquid water on the planet and the possibility of finding Martian fossils or at least records of prebiotic evolution. The evaluation of techniques to search for life (extinct or extant) has continued, as has the examination of sites for exobiological studies. Other issues of general interest include the data obtained with terrestrial models for survival on Mars. Both simulation experiments in the laboratory and observations in extremely dry deserts (Antarctica, Atacama), suggest that survival of dormant life for geologically significant time periods appears quite unlikely, unless the dormant organisms are "revived" after at least a few decades so that they can repair the DNA damage that accumulates in extreme dryness. Other issues include the question of Mars colonization and the importance of planetary protection provisions for Mars missions.

The Mars Task Group was recently created recently and is designed to work with other COSPAR Commissions in considering interdisciplinary objectives for future Mars missions. In the case of life sciences COSPAR is most interested in the search for life-related organic molecules not found by the Viking Mission. COSPAR is also interested in the potential for a fossil record on Mars which would include fossil evidence of ancient organisms which may have once existed but no longer survive. In order to achieve these objectives COSPAR has held a series of meetings discussing how such searches might be done on future missions and the need to prevent serious contamination of Mars with terrestrial life forms and organic debris. These meetings have been international in nature and will be continued.

Regarding Titan, the atmospheric conditions of this Saturnian satellite have been further evaluated for the planned Cassini mission. Actual questions were the composition of the organic haze, the meteorological conditions (e.g., rain of small methane droplets) and aspects of prebiotic chemistry.

The organic inventory of comets and their possible role in prebiotic evolution on the early Earth is still being evaluated in view of the studies of comet Halley.

The SETI programme is still in progress and thus far no "intelligent" radio sources have been detected.

As noted elsewhere in this report, the first flight of ESA's European Retrievable Carrier (EURECA) platform was dedicated to microgravity related research. The platform was launched in August 1992 from the United States Space Shuttle and, after deployment in space, it was boosted into a higher orbit where it stayed for almost 10 months; the subsequent retrieval by another Shuttle was successfully completed in June 1993. Although primarily addressing questions in fundamental physics associated with material sciences, the platform also housed the Exobiology and Radiation Assembly (ERA) which supported research into space radiation effects and other space environmental factors relating to the origin and evolution of life. All biological samples were returned to Earth for detailed analysis in the respective laboratories. The response of resistant micro-organisms and biomolecules to the harsh environment of space was also investigated on Spacelab Mission D2.

2. Origins of Life

Progress has been achieved both regarding the formation of monomeric building blocks and that of polymers believed to have been essential for the first life. The major developments in the origins of life field were presented at the 7th Meeting of the International Society for the Studies of the Origins of Life in Barcelona, Spain, on July 4-9, 1993.

The traditional view of small molecules is that the formation of the simple organics essential for the origin of life formed by atmospheric lightning discharges suffers from the absence of reduced reactants, e.g. methane, ammonia and hydrogen. Consequently, the possibility that the organics necessary for the first life came from other sources, especially comets or hydrothermal systems, was examined in detail in 1993. Constraints on the delivery of organics and the possible destruction and synthesis of organics during cometary impacts have been evaluated. It has been concluded that cometary delivery of organics is at least as plausible as their synthesis by lightning discharges.

Hydrothermal systems are evidenced today by the "black smokers" undersea. These marine systems may also have been a source of organics on the primitive Earth. They consist of vast areas of fluid circulating through clays and other mineral assemblages. The redox potential in these systems is strongly reducing. They work as a flow reactor in which more oxidized gases such as CO and CO_2 are reduced. Because of mineral catalysis, the resultant

products are converted to more complex structures. However, the matter is controversial because amino acids and other biomonomers are not stable under "black smoker" conditions. The sharp temperature gradients, however, may serve to initiate and quench all chemical processes, and freeze intermediate states far from equilibrium. Other new ideas include the organization and possible reaction of biomonomers at interfaces. In one proposal the interface is the surface of bubbles and in other micelles. Chemical experiments have been conducted in micellular systems to show the acceleration of the rate of reactions which lead to the formation of new micelles.

A principal area of polymer research activity is the synthesis and replication of RNA-like oligomers that may have resulted in an "RNA-World" (a protobiological world in which RNA species were the principal catalytic and informational macromolecules). The montmorillonite catalyzed conversion of monomers to RNA oligomers in aqueous solution has been extended from 5'-AMP to activated derivatives of 5'-UMO and 5'-CMP.

Oligomers (15-20 m in length) of cytidylic acid have been formed and have been used for the formation of the complementary G oligomers. The UO22+ catalyzed formation of 2',5'-linked oligomers has also been extended to U and C oligomers. Many in the field feel that simpler precursors to RNA were formed on the primitive Earth prior to the contemporary complex RNA structures. Several approaches to the formation of the pre-RNAs have been proposed and studied. These include the use of pentaerythritol as a precursor to ribose and barbituric acid derivatives. Hydroxymethyluracil and urazoles are proposed as precursors for the standard pyrimidine bases. Some initial studies on the formation of polymers based on barbituric acid derivatives of pentaerythritol appear promising. In related studies the chemical synthesis of RNA polymers was undertaken where hexose sugars were substituted for ribose sugars. The Watson-Crick associations of these polymers and the conformations of the helical structures formed have been studied. New theoretical studies on autocatalysis, an essential process in amplification of RNA have been reported. The directed evolution of RNA molecules in test tube experiments has led to the formation of ribozymes which replicate and ligate RNA oligomers and which utilize Ca_2+ in place of Mg_2+ as a cofactor. The idea of an "RNA-World", however, is controversial. One school of thought suggests that protoproteins preceded nucleic acids or their analogues while others argue that there was a simultaneous and cooperative evolution of protoproteins and nucleic acids.

D. Natural and Artificial Ecosystems

1. Biospherics

Most of theoretical biosphere models are used to understand climate in the past and to predict the future consequences of global changes. Geochemical data obtained both from polar ice and from deep ocean deposits testify to the concordance between atmospheric carbon dioxide variations and past temperature changes on the Earth. However, calculations of models indicate that the green house effect of CO_2 (and similar other gases) per itself can only explain a small part of the change in the Earth's thermal balance. An amplifier process is postulated. An idea that is gaining greater acceptance is that the terrestrial plant ecosystem could play the role of

amplifier of any imbalance. Modelers, using mainly remote sensing data, also need precise data relating the main types of ecosystems to climatic and atmospheric parameters (mainly CO_2, temperature and water availability), to introduce into models of terrestrial ecosystems. It is hoped that artificial ecosystems will be a source of precise and reproducible data in that field.

A recent experiment, studying the effect of CO_2 doubling on an artificial tropical ecosystem showed that no significant differences in stand biomass, leaf area index, nitrogen or water consumption were detected between ambient and elevated CO_2 treatments. The tendency to increase biomass accumulation was compensated by the stimulation of carbon losses by the rhizosphere activity. This study points at the inadequacy of scaling-up from physiological baselines to ecosystems without accounting for interactions among components. It emphasizes the urgent need of scientific experimentation with monitored natural ecosystems or with artificial ecosystems in biospheric research.

2. Controlled Ecological Life Support System

During the reporting period, advances have been observed in the development of studies related to bioregenerative methods of life support. There are fewer and fewer gaps between engineering studies of advanced life support systems and the concept of controlled ecological life support system.

As mentioned above, a part of controlled ecological life support systems (CELSS) studies concerns also general problems of plant physiology and terrestrial ecosystems. Problems of matter circulation, stability, control and modelling are intensively studied. The most important compartment which characterize CELSS by comparison to physico-chemical regenerative systems is the compartment of food production by plants or algae cultivation. The interaction between plants and microbes and the effect of gas traces on plants are among the important scientific studies recently initiated by the CELSS programme.

Naturally, practical applications in space are linked to the projects of long term exploration on the Moon or Mars, but terrestrial projects, for example in the US Arctic base are seriously studied.

VII. MATERIALS SCIENCES IN SPACE

Microgravity research is scientific investigation conducted in a gravitational field that is a small fraction of the gravitational acceleration on Earth. Gravity is certainly a weak force compared e.g. to atomic binding forces. Therefore, the role of gravity in physical phenomena is important only when stronger forces are in equilibrium or when special circumstances arise. The goal of materials science research in space is to use the unique experimental environment to study fundamental phenomena during solidification of melts, crystal growth, combustion, and to determine thermophysical properties of fluids. Within the two main missions in 1993 involved in this area, Spacelab-D2 and EURECA, nearly 200 different experiments were performed. Compared to former Spacelab missions, it can be seen that the number of materials science

experiments decreased slightly whereas the number of life science experiments was increased. Overall it was a very successful year for materials sciences research in space.

A. Materials Science Research

The particular interest in this field is the understanding of the roles of buoyancy-driven convection, sedimentation, and hydrostatic pressure in the processing of alloys, composites, ceramics, and polymers.

The most important mission for the German Space Agency (DARA) and the German Aerospace Research Establishment (DLR) in 1993 was the Spacelab-D2 mission, which was launched on 26 April and was completed on 5 May. German universities, institutes, research establishments and industries as well as those of other countries were involved in this mission. ESA and NASA used this flight to further their microgravity programmes, and Japan provided some industrial experiments.

During the D2-mission more than 70 different materials science experiments were performed, most of them successfully. Concerning materials science research, 23 different experiments were performed during the mission in the material science laboratory facility (Werkstofflabor) and in the material science facility (MEDEA). Five experiments were related to diffusive transport in melts of salts, metals, alloys and electronic materials. The latter was a Japanese experiment. There was one experiment on nucleation of undercooled alloys, six on solidification front dynamics of alloys, salts and electronic materials, four on the phase separation behaviour in composite melts like monotectic and dispersion alloys, and seven on crystal growth of electronic materials melts, vapours and solutions, e.g. GaAs. Some of these crystal growth experiments were conducted out using the travelling heater method and floating zone method.

Within the German MAUS project, which is part of the German materials science programme, two experiments related to diffusion in glass melts (ionic diffusion and gas diffusion) and a third, related to boiling effects of fluids (pool boiling) were performed as autonomous experiments during the Spacelab-D2 mission. Due to technical failures, however, neither glass experiment was correctly executed.

After nearly eleven months in orbit the EURECA platform was successfully retrieved and returned to Earth on 1 July. The highest number of experiments in the materials science field were related to solidification and crystal growth effects in electronic materials, alloys and proteins. These experiments were conducted in the microgravity core payload of this free-flying platform in several multiuser facilities such as the Automatic Mirror Furnace (AMF), the Multi-Furnace Assembly (MFA), which has 12 different furnaces, the Solution Growth Facility (SGF) where the French Soret Coefficient Measurement reactor (SCM) was situated, and the Protein Crystallization Facility (PCF).

Crystallization was one of the main topics addressed during this mission. Numerous crystal growth experiments have been conducted using the AMF (23 different samples) for melt,

solution and vapour growth, the MFA (about 6 experiments), the SGF (4 different experiments) and the PCF (12 independent experiments).

Wetting behavior of metallic melts on ceramic materials was studied by an Italian experiment in the MFA. Three independent experiments with nine samples for liquid phase sintering of the WC-Co system were conducted in the MFA. Further, in this facility a number of experiments with composites dedicated to a better understanding of sedimentation, hydrostatic pressure and convection effects in fiber dispersions and high porosity alloys were executed. Whereas the analysis of the samples and experiments continues, important experimental data had been available during the flight by telemetry. Therefore, after the pre-analysis of the data at the beginning of this year, it seems that this mission was highly successful.

A German experiment on phase separation in glass melts was conducted on the Russian Mir Space Station.

NASA, ESA, DARA, CSA and NASDA continued their sounding rocket experiment programme. Within the German sounding rocket program TEXUS 30 was launched on 2 May, with six experimental payloads. One directional solidification experiment in the Ge-Si system was also performed.

B. Biotechnology Research

Biotechnology encompasses the sciences based on molecular biology and the technological developments needed to convert inventions into products. Biological microgravity research is generally divided into the study of isolated biomacromolecules like proteins and their assemblies, and cells in controlled fluid and chemical environments. Microgravity research to date has indicated that space-grown protein crystals may yield a better structural information than can be obtained from crystals grown on Earth because of the crystal size which should be more than 0.1 mm. Nearly 10 biotechnology experiments were performed during the Spacelab D2-mission. Crystallization of ribosomal particles, nucleic acids and proteins was investigated by two experiments in the cryostat device of the Werkstofflabor facility. Cell fusion processes and cell culture were studied in two experiments in the electrical cell fusion device of the Biolab facility. Some seven experiments investigating cell functions were conducted in the Biolab facility. The goal of these experiments was a better understanding of the convection transport influence in cells referred to their growth and other functions. Here, microgravity may have a strong effect on the productivity of bacteria and other cells. TEXUS 30 also had two biotechnical experiments onboard, investigating cell functions.

Twelve protein crystal growth experiments were conducted the PCF on the EURECA mission. Five different investigators from four European countries used this facility, each one using a different protein.

C. Fluid Physics and Transport Phenomena

Fluid and interfacial transport processes are ubiquitous throughout materials and biological systems. Gravitational effects influence these processes through buoyancy-driven convection, sedimentation of particles, and the distortion of fluid interfaces by hydrostatic pressure. Gravitational effects add complexity, and potentially mask other physicochemical phenomena. Experiments in a microgravity environment provide conditions for unraveling these complex transport processes in many systems. This area is one of the best developed fields of microgravity research. During the D2-mission this research field was represented by 12 different experiments in different facilities, including one autonomous MAUS experiment from Germany investigating pool boiling. A second experiment from the same investigator, concerning hysteresis effects of the specific heat at the critical point, was executed in the MEDEA facility's High Precision Thermostat.

Three diffusion experiments in salt melts and solutions were conducted in the Holographic experiment facility and the Werkstofflabor. In the latter facility two capillarity and three marangoni convection experiments took place in the Fluid Physics Module. Stability of long liquid columns, liquid column resonances, Marangoni-Benard instabilities and the onset of oscillatory Marangoni flows were investigated. Within the Holographic facility, a further Marangoni convection experiment was also conducted.

An interesting fluid physics experiment was performed during the TEXUS 30 flight. The purpose was to determine the influence of buoyancy convection in a liquid with magnetic colloids. Together with an experiment series in the Bremen drop tower which was performed as pre- and supplementary experiments, the on-going analysis is expected to yield interesting results.

Numerous experiments in this field were also executed in several facilities as part of the EURECA mission. The low level of residual acceleration together with the long duration made this mission particularly suitable for diffusion experiments. Therefore seven experiments studied thermodiffusion, Ostwald ripening, and other diffusion effects in melts and solutions.

The High Precision Thermostat was dedicated to the study of fundamental phenomena involved in physical absorption which can only be performed with homogeneously critical fluids, i.e., in microgravity. The initial results of this German experiment indicated that the discrepancy between theoretical predictions and experimental measurements is not due to gravity effects. Another instrument on EURECA was the Surface Force and Adhesion device which enabled the study of collision dynamics at very low impact velocities.

The absence of hydrostatic pressure implies that the shape of liquid columns is determined by capillary forces only. Two such experiments were performed in the AMF and the MFA.

D. Combustion Research

Microgravity experimentation in combustion offers a variety of simplifications compared to experiments done on Earth. These include a reduction of dimensionality, the inhibition of settling effects for multiphase phenomena, and a substantial reduction of buoyancy forces. Ground-based and space-based experiments focused on studies of the processes of ignition, flame spreading, flame extinction and the physicochemical characteristics of flames. While in most cases these experiments need only a short time, several combustion experiment series were performed in 1993 in microgravity facilities such as the German drop tower at Bremen, the Japanese drop shaft at Kamisunagawa, as well as on parabolic flights.

VIII. SATELLITE DYNAMICS

In 1993 the new Stella satellite for geodynamic research was launched on the French SPOT-3 satellite. It adds to the achievements of previous geodynamic satellites like Starlette, the Laser Geodynamics Satellite (LAGEOS-I), LAGEOS-II, Etalon I, Etalon II, AJISAI, TOPEX/Poseidon, and ERS-1 which were launched in previous years, and which are still producing useful data. The analysis of the vast amounts of tracking data acquired from these satellites is being pursued with increased intensity. Some of these analyses are described in more detail below.

A. Oceanographic and Geodetic Satellites

The joint France-United States TOPEX/Poseidon spacecraft, which was launched in August 1992 to measure the Earth's ocean surface topography using radar altimetry, began the operational phase of its mission in late September, 1992. The two radar altimeters on the Topex/Poseidon and the radar altimeter on the ERS-1 have been continuously monitoring long-wavelength ocean dynamics. In order to gain maximum benefit from the altimetry data, unprecedented orbit accuracy has been achieved. This has necessitated the use of highly accurate, globally-distributed tracking data as well as extremely precise models for both the gravitational and non-gravitational forces acting on the satellite. These models were improved by using information in the Topex/Poseidon tracking data from the first six months of the mission. In addition to the two altimeters, Topex/Poseidon carries laser retro-reflectors, and the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) instrument, GPS and a Tracking and Delay Relay Satellite System (TDRSS) systems which together are capable of providing precise orbit determination information. This is the first time so many different tracking systems have been integrated onto one satellite platform providing a unique opportunity for comparing ephemerides from the different data types. Since March 1993, NASA's Goddard Space Flight Center (GSFC) has been operationally determining and distributing a 10 day Topex/Poseidon precision orbit ephemeris (POE) to be put on mission geophysical data records (GDR's) for NASA. The POEs are determined using satellite laser ranging (SLR) and DORIS data from worldwide networks, which fit respectively to 4.4 cm and 0.55 mm/sec. The average RMS radial difference between DORIS-only and SLR-only orbit solutions is about 3 cm. The

GSFC POE differs little from solutions independently determined at CNES in France and at the CSR at the University of Texas at Austin, showing a radial RMS difference of 3 cm and 2 cm respectively. With Topex/Poseidon in constant view of four or more GPS satellites, the GPS observations provide excellent geometric coverage of the Topex/Poseidon orbit. The radial RMS difference between available GPS orbits and POEs is at the 4 cm level. These and other tests indicate that the POE radial orbit errors are consistently at or below the 5 cm RMS level, far exceeding mission requirements. Construction of near real-time maps of the sea surface topography are possible with these accurate Topex/Poseidon ephemerides and precise altimetric measurements. Important dynamic oceanographic features, such as Kelvin waves, may be observed as they move across the ocean basins. This will facilitate understanding of the temporal ocean processes and provide valuable information for the study of global change.

LAGEOS II, launched in October 1992, has been tracked by a globally distributed network of 42 SLR sites. The SLR data from this satellite are contributing to knowledge about the tectonic motions of the Earth's crust and Earth orientation parameters which are closely related to the continuous changes in the distribution of the air and sea masses. Preliminary orbital dynamic and geodynamic results are showing excellent agreement with those obtained from LAGEOS I.

B. Improved Terrestrial Reference Frame

The International Earth Rotation Service (IERS) has generated an improved definition of the Conventional Terrestrial Reference System (CTRS), based on contributions from many space measuring techniques such as SLR and VLBI. This year marks the first that time IERS will have a complete year of GPS data from a global network of tracking stations to incorporate into a new CTRS definition. The analysis of SLR data, collected by a global network of laser ranging stations make significant contributions to the definition of the CTRS.

Many different international groups are involved in this analysis of the various types of data. An important goal is the establishment of the positions for the global International GPS Service (IGS) network in coordination with the Fiducial Laboratories for International Natural Network (FLINN) to the centimetre level. Considerable progress has been made towards this goal. The coordinates of the pole and universal time are currently being determined with an accuracy of 0.2 milliarcsecond and 0.05 millisecond, respectively.

C. Applications of GPS to Geodynamics

As of October 1993 there were 25 operational GPS spacecraft. This year also marked the first full year of the operation of a global GPS tracking network in preparation of the establishment of an IGS, as recommended by the International Association of Geodesy (IAG). There are now more than 40 globally distributed high quality GPS receivers operating continuously. The tracking data are transferred through computer networks to several processing centres, which generate precise GPS orbits and Earth rotation parameters products a few days after the data were obtained. The 50 cm accuracy of the recovered GPS orbits is quite an

improvement over the accuracy of the broadcast ephemerides. The quality of the polar motion parameters is at least comparable to SLR, but the temporal resolution is much higher, due to the continuous tracking coverage. This successful year should lead the IAG to agree to have the IGS become a permanent service beginning January 1, 1994. The improvements in GPS orbit accuracy and the global coverage have also resulted in better results for the station position estimation. The United States Jet Propulsion Laboratory (JPL) has reported IGS station position precision of several centimeteres. For a regional network, the precision of GPS station position has been shown to be better than 1 cm. This is of great importance for regional geodynamic studies. As a complementary technique to SLR and VLBI, GPS promises to provide improvements to the temporal and spatial resolution of the geodynamic networks. In 1993, there were significant improvements in the automation of the techniques to handle the vast amounts of GPS tracking data.

D. New Geopotential Models

Efforts to improve knowledge of the Earth's gravity field have resulted in a new model containing coefficients up to a degree 70. This geopotential model, called the Joint Gravity Model 2 (JGM-2), was produced by a team of investigators from the NASA GSFC, the University of Texas at Austin, the Ohio State University, and CNES. The JGM-2 model was developed by reprocessing the data contained in the previous JGM-1 model with many improvements in supporting constants and models. In addition, SLR and DORIS tracking of Topex/Poseidon were added to the model. A benefit of the DORIS tracking system is the all-weather capability and good global distribution of approximately 45 tracking beacons. This new field makes significant contributions to accurate orbit determination of other satellites and to oceanographic studies, which require good geoid models. The latest models currently allow a radial orbit accuracy of several centimetre for satellites such as Topex/Poseidon and ERS- 1, at altitudes of 1300 and 800 km, respectively.

E. Improved Models for the Gravity and the Topographic Fields of Mars and Venus

A new gravity model for Mars was produced by the NASA GSFC. The model, designated Goddard Mars Model 1 (GMM-1) is complete in spherical harmonics to degree 50. The model was determined by reprocessing the historical tracking data from the Mariner-9, Viking-1, and Viking-2 missions. Improved gravity models have also been produced for Venus. NASA has also produced the Goddard Venus Model 1 (GVM-1) which is complete to degree 50 in spherical harmonics. GVM-1 was produced from the historical tracking data of the Pioneer Venus Orbiter (PVO). In addition, the JPL has produced similar models incorporating the PVO data and some of the early Magellan tracking data. Both GSFC and JPL are expected to produce further improvements to the gravity model of Venus using post-aerobraking Magellan tracking data.

F. Future Satellite Missions

Still scheduled for launch later this year are two satellites with orbit dynamic and geodetic applications. The United States MSTI-2 satellite, and Russia's METEOR-3 satellite will both carry laser retror-eflectors and METEOR-3 will also carry the Precise Range and Range-rate Equipment (PRARE) tracking system. The Clementine Mission to the Moon and the asteroid 1620 Geographos will be launched in early 1994. After spending 73 days in Lunar orbit Clementine will fly-by the asteroid. The lunar portion of the mission will allow the determination of a global map of lunar topography, and allow the long-wavelength topographic and gravitational fields of the Moon to be compared in a meaningful way for the first time. Because the Mars Observer spacecraft which was launched in September 1992 was lost during a maneuver in August 1993, scientists are currently studying plans to send other missions to Mars. Current scenarios call for a return to Mars during the 1996 launch opportunity. All Mars Observer instruments will be rebuilt to be flown on either one of two possible spacecraft.

IX. SCIENTIFIC BALLOONING

A 100 per cent mission success rate is the remarkable element in the development of scientific ballooning in recent years. This is compared with a success rate of less than 80 per cent in the 1980's. This change is the result of continuous efforts to perform structure studies and to improve balloon materials and manufacturing technologies, which is mainly being done by groups in France and the United States, China, India and Russia are also contributing to this field, and they are capable of manufacturing large balloons using their own improved materials.

The United States has succeeded in flying small super-pressure balloons made of bi-axially oriented Nylon film, and have indicated a possible development of more capable super-pressure balloons using these films. Japanese groups are also investigating possible new films which preferentially absorb the infrared radiation at balloon altitude, noting a possibility of saving the ballast consumption for balloons with this envelope in long duration flights. These improvements of balloon technologies were the pre-condition for the successful performance of balloon campaigns in various locations in the world. Some outstanding events are mentioned below.

The European Arctic Campaign was conducted during 1991 and 1992. It was organized by CNES and involved 15 laboratories from various European countries including Russia. In this campaign 48 balloons were launched from the ESRANGE facility at Kiruna, Sweden, and were successfully operated without any failure. In cooperation with satellite, sounding rocket and ground-based experiments in the polar region, the minor atmospheric constituents such as ozone as well as the global motions of the atmosphere were studied. The payloads were recovered in the territories of Finland, Sweden and Russia. Because of the outstanding success of this campaign, future coordinated campaigns in Europe have been discussed in a workshop during a recent ESA symposium in Montreux, Switzerland.

Trans-mediterranean flights have also been conducted each year in a collaborative programme between France, Italy and Spain, with payload recovery taking place in Spain. Almost ten flights, each lasting more than ten hours, have been scheduled every year. Various other European countries also participate in this programme.

Two long duration flight campaigns were conducted in Antarctica. One programme was conducted by a Japanese group in a collaboration between the National Polar Institute and ISAS. The balloons were launched from Showa Station, and remained aloft for almost two weeks, returning to the launching area after the circum-polar flights. Such long duration flights are possible due to the absence of sunsets in the summer season in the Antarctica, and thus essentially no ballast is needed to keep the level altitude of the balloons.

Motivated by these Japanese studies, another campaign has been conducted by NASA. Balloons were launched from the MacMurdo Base, and the flights lasted nearly ten days before returning to their launch site after having completed a circle around the south pole. The payloads were recovered near MacMurdo. Because of the impressive success of long duration flights in this programme, NASA is now planning to perform a long-term programme for long duration flight observations. The programme, named GOAL, is to observe solar phenomena, the cosmic ray spectrum and composition at extremely high energy, which can only be achieved by observations with extremely long duration. Because of the high cost efficiency of this programme, compared with other space programmes, there are high hopes that this programme will be initiated in the near future. The advantages of this programme and possible candidates for observations were discussed in a workshop of the International Cosmic Ray Conference at Calgary, Canada.

Another campaign of long duration flights was discussed between Russia and the United States. It involves launches from Canada and recoveries in western Russia. The Russian group has also been operating long duration flights from Kamchatka to Ural lasting about 5-6 days. Other international efforts include a cooperative programme between China and Russia, with the balloons being launched from China and payload recovery taking place in western Russia. These flights last almost four days.

Beside these activities, NASA is conducting campaigns at New Mexico, United States, and Lynn Lake, Canada, for scientific observations in astrophysics and atmospheric science. As a part of this programme the Japanese super conducting magnet spectrometer (BESS), developed in collaboration with scientists from the United States to observe anti-protons in cosmic rays, was successfully used at Lynn Lake, Canada, in summer 1993.

A summary of international activities in scientific ballooning must also include India, which is still active in this field. Some 420 flights have been launched from the Hyderabad launch facility since its establishment in 1969. Taking advantage of the low latitude (high magnetic cut-off energy of cosmic rays) many experiments were conducted in the fields of X-rays, gamma-rays, cosmic rays and infrared. A number of balloon flights are also devoted to

atmospheric sciences. Some of these were performed in collaboration with other countries, including Japan and the United States.

A different approach to balloon design has been adopted by a French group which has been making efforts to improve the performance of their balloons called "Mongolfiere Infra Rouge", which are essentially hot air balloons utilising the infrared spectrum at balloon altitudes. Many flights have been conducted in the past, with some lasting more than a month, over the South Pacific and southern Indian Ocean. A successful test flight was recently conducted over the Arctic.

Recent interest has also focused on the subject of balloons flying in other planetary atmospheres. Venus low-altitude balloons have been studied by French and Japanese groups. In 1985 groups from France, Russia, and the United States groups very successfully operated balloons appropriate for the Venusian atmosphere, floating at high altitude. Further studies on the Martian low altitude balloons to be launched 1996 are now under development by groups in France and the United States.

CONTRIBUTORS

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ACRONYMS AND ABBREVIATIONS

AASE-II	Second Airborne Arctic Stratospheric Expedition
AIRSAR	Airborne Synthetic Aperture Radar
Ajisai	(Hydrangea flower) Japanese experimental geodetic satellite
AMF	Automatic Mirror Furnace
AMSU	Advanced Microwave Sounding Unit
AOT	Aerosol Optical Thickness
APEX	Active Plasma Experiment Program
ATLAS	Atmospheric Laboratory for Applications and Science (USA)
ATSR	Along Track Scanning Radiometer
AU	Astronomical Unit
AVHRR	Advanced Very High Resolution Radiometer
AXAF	Advanced X-ray Astrophysics Facility
BASE	Burst and Transient Source Experiment
BESS	Japanese super conducting magnet spectrometer
BOREAS	Boreal Ecosystems Atmospheric Study
CADRE	Coupling and Dynamics in Regions Equatorial
CAPE	Crop Acreage and Production Estimation
CCD	Charged Coupled Device
CDS	Coronal Diagnostic Spectrometer
CEC	Commission of the European Communities
CEDAR	Coupling, Energetics, and Dynamics of Atmospheric Regions
CELIAS	Charge Element and Isotope Analysis
CELSS	Controlled Ecological Life Support System
CEOS	Committee on Earth Observations Satellites
CI	Subclass of chondritic meteorites
CIRA	COSPAR International Reference Atmosphere
CIV	Critical Ionization Velocity
CNES	Centre National d'Etudes Spatiales
COBE	Cosmic Background Explorer
COMPTEL	Imaging Compton Telescope
COSPAR	Committee on Space Research
COSTEP	Comprehensive Suprathermal and Energetic Particle Analyzer
CRRES	Combined Release and Radiation Effects Satellite
CS	Catalog Subgroup
CSA	Canadian Space Agency
CTRS	Conventional Terrestrial Reference System
CZCS	Coastal Zone Color Scanner
DARA	German Space Agency
DLR	German Aerospace Research Establishment
DMSP	Defense Meteorological Satellite Program (United States Air Force)

DNA	Deoxyribonucleic Acid
DORIS	Doppler Orbitography and Radio-positioning Integrated by Satellite
EASOE	European Arctic Stratospheric Ozone Experiment
EGRET	Energetic Gamma-ray Experiment Telescope
EISCAT	European Incoherent Scatter Facility
EIT	Extreme Ultraviolet Imaging Telescope
ERA	Exobiology and Radiation Assembly
ERNE	Energetic and Relativistic Nuclei and Electron Experiment
ERS	Earth Remote Sensing Satellite
ESA	European Space Agency
ESTEC	European Space Research and Technological Centre
EURECA	European Retrievable Carrier
EUVE	Extreme Ultra-Violet Explorer
EVA	Extra-vehicular Activities
FAO	Food and Agriculture Organisation
FAST	Fast Auroral Snapshot Explorer
FIRST	Far Infrared Sub-mm Telescope
FLINN	Fiducial Laboratory for International Natural Network
FRAM	Fine Resolution Antarctic Model (United Kingdom)
FUSE	Far Ultraviolet Explorer
GDR	Geophysical Data Records
GEOSCOPE	Interactive Global Exchange Encyclopedia (Canada)
GEWEX	Global Energy and Water Cycle Experiment
GGS	Global Geospace System
GMM	Goddard Mars Model
GOAL	Galactic Origin and Acceleration Limit
GOES	Geostationary Operational Environmental Satellite
GOLF	Global Oscillations at Low Frequencies
GOME	Global Ocean Monitoring Experiment
GPS	Global Positioning System
GRO	Gamma-Ray Observatory
GSFC	Goddard Space Flight Center
GSI	Gesellschaft für Schwerionenforschung MBH
GTS	Global Telecommunications System
GVM	Goddard Venus Model
HDP	Human Dimensions of Global Environment Change Programme
HF	High Frequency
HIREGS	High Resolution Gamma-Ray and Hard X-ray Spectrometer
HPT	High Precision Thermostat
HST	Hubble Space Telescope
IAF	International Astronautical Federation
IAG	International Association of Geodesy
IASTP	Inter-Agency Solar-Terrestrial Program
ICSU	International Council of Scientific Unions

ICTP	International Center for Theoretical Physics
IDP	Interplanetary dust particles
IERS	International Earth Rotation Service
IGBP	International Geosphere-Biosphere Programme
IGS	International GPS Service
IKI	Institute for Space Research (Russia)
IML	International Microgravity Laboratory
INSAT	Indian satellite
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IRI	International Reference Ionosphere
IRS	Indian Remote Sensing satellite
ISAS	Institute of Space and Astronautical Science
ISLSCP	International Satellite Cloud Climatology Project
ISO	Infrared Space Observatory
ISTP	International Solar-Terrestrial Program
ISY	International Space Year
IUE	International Ultraviolet Explorer
JERS-1	Japanese Earth Remote Sensing Satellite
JGM	Joint Gravity Model
JGOFS	Joint Global Ocean Flux Study
JPL	Jet Propulsion Laboratory
LAGEOS	Laser Geodynamic Satellite
LASCO	White Light and Spectrometric Coronograph
LDEF	Long Duration Exposure Facility (NASA)
LEO	Low Earth Orbit
LISS	Linear Imaging Self-scanning Sensor
MAP	Middle Atmosphere Program
MAPS	Measurement of Air Pollution from Satellites
MARSNET	Mars Network
MAUS	Materialwissenschaftliche autonome Experimente unter Schwerelosigkeit
MDC	Munich Dust Counter
MDI:SOI	Michelson Doppler Imager
MEDEA	Material science facility
MESUR	Mars Environmental Survey
MFA	Multi Furnace Assembly
MLTCS	Mesosphere, Lower Thermosphere Coupling Study
MO	Mars Observer
MSS	Multi-spectral Scanner System
MSTI	Military Seeker Technology Integration
MSU	Microwave Sounding Unit
MVIRI	Meteosat Visible and Infrared Imager
NASA	National Aeronautics and Space Administration (United States)
NASDA	National Space Development Agency (Japan)
NLC	Noctilucent Clouds

NOAA	National Oceanographic and Atmospheric Administration (United States)
NSCORT	NASA Specialized Centres of Research and Training
ORA	Occultation Radiometer
OSL	Orbiting Solar Laboratory
OSSE	Oriented Scintillation Spectrometer Experiment
PCF	Protein Crystallization Facility
PMSE	Polar Mesosphere Summer Echoes
POE	Precision Orbit Ephemeris
PRARE	Precise Range and Range-rate Equipment
PRISMA	Probing Rotation and Interior of Stars
PSRDC	Panel on Space Research in Developing Countries
PVO	Pioneer Venus Orbiter
QBO	Quasi-biennial Oscillation
RAIDS	Remote Atmospheric and Ionospheric Detection System
RMS	Root Mean Square
RNA	Ribonucleic Acid
ROSETTA	Re-scoped version of the original ESA-NASA Comet Sample Return Mission
SAO	Semi-annual Oscillation
SAR	Synthetic Aperture Radar
SAREX	Coordinated Synthetic Aperture Radar Experiment
SAX	X-ray Astronomy Satellite
SBUV	Solar Backscatter Ultraviolet
SCALE	SCAttering Layer Experiment
ScaRab	Earth Scattered Radiation Budget instrument (France, Germany, Russia)
SCM	Soret Coefficient Measurement
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SeaWIFS	Sea-viewing Wide Field Sensor
SEE	Stimulated Electromagnetic Emissions
SEM	Solar Extreme Ultraviolet Monitor
SEPAC	Space Experiments with Particle Accelerators
SERC	Science and Engineering Research Council
SETI	Search for Extraterrestrial Intelligence
SFA	Surface Force and Adhesion
SGF	Solution Growth Facility
SIR-C	Third flight of the Shuttle Imaging Radar
SIRTF	Space Infrared Telescope Facility
SLAR	Side Looking Airborne Radar
SLR	Satellite Laser Ranging
SLS	Spacelab Life Sciences
SMM	Solar Maximum Mission
SMY	Solar Maximum Year
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOHO	Solar and Heliospheric Observatory
SPOT	Satellite pour l'Observation de la Terre

SSM/I	Special Sensor Microwave Imager
SSMR	Special Sensor Microwave Radiometer
SST	Sea Surface Temperature
STEP	Solar Terrestrial Energy Program
SUMER	Solar Ultraviolet Emitted Radiation
SWAN	Solar Wind Anisotropies
SXT	Soft X-ray Telescope
TDRSS	Tracking and Data Relay Satellite System
TEXUS	Technologische Experimente unter Schwerelosigkeit
TIGER	Terrestrial Initiative in Global Environmental Research (United Kingdom)
TIROS	Television and Infrared Observations Satellite
TOPEX	Ocean Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TREES	Tropical Ecosystem Environment Observations by Satellites
TSS	Tethered Sub-satellite (United States)
UARS	Upper Atmosphere Research Satellite
UCWE	Upward Coupling of Wave Energy
UNESCO	United Nations Educational, Scientific and Cultural Organization
UV	Ultraviolet
UVCS	Ultraviolet Coronograph Spectrometer
VAS	Visible and Infrared Spin Scan Radiometer
VHF	Very High Frequency
VHRR	Very High Resolution Radiometer
VIRGO	Variability of Solar Irradiance
VLBI	Very Long Base Interferometry
VOA	Voice of America
WCRP	World Climate Research Programme
WGD	Working Group on Data
XMM	X-ray Multi-Mirror
XTE	X-ray Timing Explorer